

बीड्स से बीज सुखाने के प्रणाली की निष्पादन मूल्यांकन

Performance evaluation of Beads Drying System

AKHOON ASRAR BASHIR



**DIVISION OF AGRICULTURAL ENGINEERING
INDIAN AGRICULTURAL RESEARCH
INSTITUTE**

**NEW DELHI -110012
2013**

VISIT...

LANZAROTE
Caliente.COM

Performance Evaluation of Beads Drying System

A Thesis

By

AKHOON ASRAR BASHIR

Submitted to the Faculty of Post-Graduate School,
Indian Agricultural Research Institute, New Delhi,
In partial fulfillment of the requirements
for the degree of

**MASTER OF TECHNOLOGY
IN
AGRICULTURAL ENGINEERING
2013**

Approved by the Advisory Committee:

Chairman:

(Dr. J. P Sinha)

Co-Chairman:

(Dr. D. V. K. Samuel)

Member:

(Dr. G. K. Jha)

Member:

(Dr. S. K. Jain)



Dr. J. P. Sinha
(Principal Scientist)
(Agricultural Processing
and Structures)

Division of Agricultural Engineering,
IARI, New Delhi-110012

CERTIFICATE

This is to certify that the thesis entitled “**Performance Evaluation of Beads Drying System**”, submitted to the Faculty of the Post-Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfillment of the requirements for the degree of **MASTER OF TECHNOLOGY** in **AGRICULTURAL ENGINEERING** embodies the results of *bona fide* research work carried out by **Mr AKHOON ASRAR BASHIR** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

It is further certified that any help or source of information that has been availed of in this connection has been duly acknowledged by him.

Date: July, 2013
Place: New Delhi

(Dr. J. P. Sinha)
Chairman
Advisory Committee



Dedicated To
...My Beloved
Grandfather...
Akhoun Ghulam Hassan

ACKNOWLEDGEMENT

All praises are due to Almighty Allah, the most merciful. He has been having undue and unconditional mercy on me all these years. None of my words can afford to pay gratitude to Him, the Exalted One. I ask His forgiveness for all my wrong deeds. Blessings of Allah be upon His last messenger, Muhammad (SAW) and his family and companions.

*It is my proud privilege to express my deep sense of gratitude and indebtedness to my mentor **Dr. J. P. Sinha**, Principal Scientist, Division of Agricultural Engineering, and chairman of my advisory committee for his inspiring and sagacious guidance, affectionate encouragement, congenial discussions, compassionate initiation and able counsel during the course of this investigation and preparation of this manuscript. I am proud to be associated with such a dynamic, experienced and benign personality.*

*I express my deep sense of gratitude and indebtedness to **Dr. D. V. K. Samuel**, Head, Division of Agricultural Engineering, IARI, New Delhi and Co-Chairman of my advisory committee for his encouragement, cooperation at every level and providing facilities for the completion of research work.*

*I am equally indebted to members of my advisory committee **Dr. G. K. Jha**, Senior Scientist, Division of Agricultural Economics and **Dr. S. K. Jain**, Principal Scientist, Division of Seed Science and Technology, IARI, New Delhi for providing helping hand and offering constructive criticism during the course of study.*

I gratefully acknowledge the help of Dr Krishan Lal, Principal Scientist, IASRI, New Delhi for his valuable suggestions at the eleventh hour.

I would fail in my endeavor without acknowledging the help and inspiration received from the Professor of our Division, Dr. Indramani Mishra. He was always there to rely upon. I am also highly indebted to all the teachers in the my division: Dr. Dipnkar De, Principal Scientist, Dr. J. K. Singh, Principal Scientist, Dr. S. S. Tomar, Principal Scientist, Dr. P. K. Sharma Principal Scientist, Dr. Adarsh Kumar, Principal Scientist, , Dr. P. K. Sahoo, Principal Scientist, Dr Tapan Khura, Senior Scientist, Er. Satish Lande, Scientist, Division of Agricultural Engineering, IARI.

The support and suggestion obtained from Dr. T. B. S. Rajput, Dr. D. K. Singh, Dr. A. K. Mishra, Dr. M. Hasan, Dr. Sarangi, and other faculties of the division of agricultural engineering were of immense help in my research work and are gratefully acknowledged.

I shall always remain thankful to Shri Poddarji, Vishwanathji, Praveenji, Lalta Prasadji, Sharmaji, Subhashji, Dharamsinghji, Satyanarayanji, Premji and Shrimati Anandiji for their willingness, unconditional and timely help and support given to me during the research work. I also express my thanks to the other staff and workers of Division of Agricultural Engineering, for their assistance and cheering me during course of my research work.

I would specially like to thank my dear seniors Arun Sir, Manoj Sir, Santosh Sir and very beloved Amita madam. Sakharam sir, Rahul Sir, Bhushan sir, and Kirti madam were always ready to lend a helping hand. I would fail in acknowledgement if I do not mention the help provided by my dear immediate seniors, Muzamil Sir, Shaym Sir, Sagar Sir, Jitendra Sir, Saci Sir and Rouf Sir. I love to mention the help provided by my dear junior Pramod. My heartfelt thanks are also to social networking media to keep me connected to friends and family dispersed throughout the length and breadth of globe. I particularly like to mention my very dearest friend Gazala for her emotional support throughout the tenure in IARI. She was always ready to do whatever was asked of her. I also thank my friend Tariq whose support came like flowing water. I also thank my classmates and very sincere friends: Navnath, Deepak, Manmohan, Srikanta, Ravi, Jiten, Pawan and Om Prakash.

I have no words to thank my dearest friend, Sumaira. She has been like a candle in the darkness. Without her support and love, my stay in IARI would not have been possible. I also wish to say a humble thanks to my family for always being there. They have no substitute in any way. My beloved sister, Misba was always a source of happiness in times of despair. I also like to thank a very special friend, Margaret, who despite thousands of miles of distance from here was always around. She was a source of joy in times of immense loneliness.

The financial help provided by ICAR in the form of JRF during the course of this study is duly acknowledged.

Date:

Place: New Delhi

(Akhoon Asrar Bashir)

LIST OF TABLES

Table No.	Title	Page
3.1.	List of equipment/instruments used and their specifications	19
3.2	Process variables and their levels	24
3.3	Experimental Layout	24-25
4.1	Process variables and their levels	33
4.2	Experimental Layout	34-35
4.3	ANOVA and regression coefficients of the second order polynomial model of the various responses for tomato seeds	36-37
4.4	ANOVA and regression coefficients of the second order polynomial of model the various responses for tomato seeds	40-41
4.5	Applied constrains to obtain optimized values of processing variables individually	42
4.6	Individual optimized responses	43
4.7	Applied constrains to obtain optimized values of processing variables and the predicted response for tomato	43
4.8	Applied constrains to obtain optimized values of processing variables and the predicted response for onion	46
5.1	Surface area of beads at different experimental levels	53
5.2	Moisture contents for tomato and onion seeds after hot air drying	53

LIST OF FIGURES

Fig No.	Title	Page
3.1	Microwave Oven	20
3.2	Hot Air Oven	20
3.3	Digital Vernier Caliper	20
3.4	Portable Data Logger	20
4.1a	Response surface plot for final moisture content of tomato seed as a function of (a) seed bead ratio and residence time	37
4.1b	(b) initial moisture content and seed bead ratio while other variables are at center point	37
4.2.a	Response surface plot for final moisture content of onion seed as a function of (a) residence time and initial moisture	37
4.2.b	(b) seed bead ratio and residence time while other variables are at centre point	37
4.3.a	Response surface plot for germination percentage of tomato seed as a function of (a) residence time and seed bead ratio	38
4.3.b	(b) initial moisture content and residence time while other variables are at centre point	38
4.4.a	Response surface plot for germination percentage of onion seed as a function of (a) residence time and seed bead ratio	38
4.4.b	(b) residence time and initial moisture content while other variables are at centre point	38
4.5.a	Response surface plot for vigour index I of tomato seed as a function of (a) residence time and seed bead ratio	38
4.5.b	(b) initial moisture content and residence time while other variables are at center point	38
4.6.a	Response surface plot for vigour index I of onion seed as a function of (a) residence time and seed bead	39
4.6.b	ratio (b) initial moisture content and residence time while other variables are at centre point	39
4.7.a	Response surface plot for vigour index II of tomato seed as a function of (a) residence time and seed bead ratio	39

4.7.b	(b) initial moisture content and residence time while other variables are at center point	39
4.8.a	Response surface plot for vigour index II of onion seed as a function of (a) residence time and seed bead ratio	39
4.8.b	(b) initial moisture content and residence time while other variables are at centre point	39
5.1	Hot air oven regeneration graph	51
5.2	Microwave oven regeneration graph	52

LIST OF ABBREVIATION

db	Dry basis
EM	Electromagnetic
FTIR	Fourier's Transform Infrared spectroscopy
GI	Galvanized Iron
g	Gram
h	Hour
I	Solar radiations, W/m ²
IARI	Indian Agricultural Research Institute
i.e.	That is
IR	Infrared
km	Kilometer
kg	Kilogram
μm	Micrometer
μg	Microgram
mm	Millimeter
m	Meter
ml	Milliliter
M.C.	Moisture content
Nm	Nanometer
RH	Relative humidity
T	Collector outlet temperature, °C
Ta	Ambient air temperature
Ts	Sheet temperature
Wb	Wet basis
W ₁	Initial weight of the sample

W_2	Final weight of the sample
A	Absorptance
E	Emmitance
Γ	Reflectance

CHAPTER 1

INTRODUCTION

India is next only to China in vegetable production with an annual production of 87.73 million tonnes from 5.86 million hectares having a share of 14.4 per cent to the world production. Vegetables play a major role for nutritional and economic security especially in Indian context, where major part of population is vegetarian. In addition, vegetables have higher productivity, shorter maturity cycle, high value and provide greater income leading to improved livelihoods. The area under vegetable cultivation has increased from 5593 thousand ha in 1991-92 to 7985 thousand ha in 2009-10. The overall growth rate of 2.08% in area, 1.64% in productivity and 3.72% in total production has been achieved during the last five years. Our demand of vegetables will be 225 million tonnes by 2020 and 350 million tonnes by 2030 (NHB, 2009). The major challenge, which lies ahead, is to develop technologies that enhance quality and productivity of vegetables under reducing land, declining natural resources and increasing biotic and abiotic stresses. More than 40 kinds of vegetables belonging to different groups, namely cucurbits, cole crops, solanaceous, root and leafy vegetables are grown in different agro-climatic situations of the country.

Tomato occupy the largest area among the vegetable crops in the world after potato. The total production of tomato of the country in 1998-1999 was 8.27 MT from an area of 0.46 Mha. It becomes an important component of dining table. Commonly, it is consumed either fresh, cooked or in the form of processed products such as jam, jelly, juice, ketchup, sauce etc. it is considered as 'poor man's apple' because of its attractive appearance and very high nutritive value, containing vitamin A, vitamin C and minerals like calcium, potassium etc. Apart from these, it also contains organic acids like citric, malic and acetic acids which found in fresh tomato fruit, promotes gastric secretion, acts as a blood purifier and works as intestinal antiseptic (Pruthi, 1993).

Onion is another important vegetable and is grown in almost all the part of India. It has made its place as an important foodstuff for vegetarian as well as non-vegetarian. Usually, it is served cooked, as a vegetable or part of a prepared savoury dish, but also be eaten raw or used for making pickles or chutneys. Several

parts of the plant have traditional place in the folk medicine, as it contains phenolics and flavonoids that have potential anti-inflammatory, anti-cholesterol, anticancer and antioxidant properties. Though India produces a significant quantity of onion, it is not regular and sufficient enough to meet the demands for both domestic requirement and exports. Amongst the onion producing countries in the world, India ranks second in area and production, the first being China. India being a second major onion producing country in the world has a productivity of 15.1 mt/ha only (Barakadeet *al.*,2011). Area under onion production worldwide is 3.72 million hectare with production to the tune of 72.34 million tonnes during 2009-10 (FAO 2008). Area under onion in India is 1042 thousand hectares with a total production value of 15 million tones with an average productivity of 15.11t/ha. Besides meeting domestic need, India exports sizeable quantity of onion, India's recent export of onion during 2009-2010 is about 16.64 lakh MT which valued of Rs. 2319.42 crores. Onion is also the most vital ingredient in Indian food, and seasonal shortages can cause price increases and social unrest. With the efforts to increase the production and productivity of tomato and onion, attention must be given to the quality seed availability and viability. These two vegetable seeds are prone to deteriorate faster under hot and humid climate.

Seed is a basic, fundamental and the cheapest input of agricultural production system. It had been observed in multi-location coordinated trials under National Seed Project that about 20-30 per cent average increase in productivity could be achieved with the use of quality seed (Chowdhary, 2004). Seed being a living entity, its moisture content is critical factor which influences its longevity as water serves as a fluid medium and stabilizes the structures of macromolecules. The moisture content of seed is one of the important factors which determine the rate of the ageing process. The high moisture content seed accelerates the respiration rate as well as activity of micro-organisms. Seed water also influences the progress and kinetics of most important biological reactions. The moisture content is frequently higher (ranging 15-18%) at the time of harvest than the optimum to obtain the best potential life of seed. It is widely accepted that drying of seed prior to storage, increases their longevity. Reducing seed moisture to low level increases storability of some seeds even under ambient conditions (Zheng, 1998).

Various methods of seed drying have been adopted ranging from traditional; sun drying to sophisticated drying systems; micro chip controlled system. Most of these methods use air as drying media and its temperature as driving factor for rate of drying. Although at higher temperature drying increases, however threat to seed quality is also associated with higher temperature. Seed quality of high value low volume seed is very sensitive with drying temperature at higher level (Javaregowda *et al.*, 1990). Among high value low volume seed, tomato and onion seeds are critical with hot air seed drying as exposure to high temperature induces heat injury to seed drastically. In turn, reduces germination, vigor and/or shelf life considerably. Commonly hot air drying systems or some expensive low temperature drying systems like refrigeration drying are being used for drying the seed. The higher temperature caused due to hot air drying is found detrimental for the seed quality (Javaregowda *et al.*, 1989) and the higher costs of other drying system hamper their adaptability by resource poor entrepreneurs. On the other hand sun drying is time and labour intensive and also weather dependent (Javaregowda *et al.*, 1989).

Alternatively desiccant drying is one option. Silica gel, Betonite, some salts (calcium sulfate, calcium chloride, sodium chloride) have been experimented for drying of seed. It has been found effective in reducing moisture content of seed (Xiorong *et al.*, 1998; Zheng *et al.*, 2001; Hu *et al.*, 2002; Zeng *et al.*, 2006). But normally desiccant drying is very slow process. Although silica gel can be regenerated by heating at a lower temperature, there is loss of water holding capacity of silica gel due to polymerization after repeated heating. It all, this method makes anon-viable option for bulk handling. Recently, zeolite beads (desiccant) has been developed which can be used as drying desiccant (Asbrouck and Taridno, 2009). Silica gel has a lower affinity for water than drying bead at the lower humidity level. Also, there is no loss of water holding capacity of drying beads after repeated regeneration process. The beads have an extremely high capacity to adsorb water, even at very low air humidity, making them optimal drying material. The adsorption process is fully reversible and of purely physical nature. The beads can be regenerated indefinitely by heating to elevated temperature. Drying beads are modified ceramic materials (aluminum silicates and zeolite) that specifically absorb water molecules and hold them very tightly in their microscopic pores. These beads are available in 5 mm and 8 mm sizes. These beads are non-toxic and essentially

inert, like ceramics. Repeated heating at high temperature does not cause any loss of water retention capacity of seed drying beads. This is in contrast to silica gel, which loses effectiveness with repeated regeneration.

Negligible information has been available on beads drying of seed. Thus there is a need to study bead drying system. Keeping the above points, the present study was made with following specific objectives:

1. Optimization of drying protocol for beads drying system.
2. Performance evaluation of beads drying for high value low volume seed.

CHAPTER 2

REVIEW OF LITERATURE

Seed water influences the progress and kinetics of the most important biological reactions. When water is a substrate, its concentration can affect the equilibrium between reactants and products. In the living tissues, water serves as a fluid medium and stabilizes the structures of macromolecules (Chai *et al.*, 1998). The moisture content and storage temperature are main factors which determine the rate of the ageing process (Bernal and Leopold, 1998). The high moisture content in seed accelerates the respiration rate as well as activity of micro-organisms. In turn, seed quality gets affected significantly with its moisture content. Every one per cent moisture content reduction double the storage period, in general (Harrington, 1960). Mechanical damage in handling and processing may occur, if the moisture content of grain is too high. Insect activity also increases as the moisture content is high. Most of the weevils and insect cannot breed properly below 8 percent moisture and tend to die. In order to control insects fumigation is required. At high moisture fumigation is also adversely affect the seed quality. Generally, moisture content at harvest maturity is higher than safe storage moisture level. Furthermore, lower moisture content seed has exhibited higher longevity. Severity of moisture content intensifies with high value low volume seed (vegetable seed) in hot and humid climatic condition. It all intensify the importance of lowering moisture content of seed i.e. drying for vegetable seed in hot and humid climatic conditions. In light of the importance of lower moisture content of seed and to investigate an efficient drying system review of the relevant literature is presented here under following subheads:

2.1. Traditional Drying

2.2. Sun Drying

2.3. Mechanical Drying

2.4. Chemical Drying

2.1 Traditional Drying

In a chronology of the early use and development of drying, Kroll *et al.* (1980) stated that cereal grains were being dried by about 100 B.C. Keey (1972) reported that kilns for drying grain were built in damp areas of Europe from the Iron Age onwards. The scientific study of drying is considered to have been begun by Van Helmant (1577-1644 A.D.), (Kroll, *et al.*, 1980). While the history of what is considered as conventional air drying is well documented, similar records of the earliest use of a heated granular medium such as sand for drying do not appear to exist. However, it is well-known that for several generations people in Africa, India and the Middle East have used this technique for roasting grains. The scientific study of different aspects of drying with a heated granular medium began in the early 1970s.

The term conduction heating for grain drying is used when heat is supplied to a solid medium which comes in contact with the grain rather than to the air surrounding it. It appears that the earliest work on grain drying by conduction heating was reported by Kelly (1939). The dryer consisted of a drum rotating above a coal burning furnace. Thus heating the grain (wheat) was performed mainly by conduction using the drum as the medium for heat transfer. The heated grain was then cooled by convection using an electric fan. The dryer had a capacity: 3.5 m³/h (100 bulbs). Kelly (1939) found that the quality of the processed wheat was satisfactory, but the amount of moisture removed was lower than required and therefore modifications were recommended.

For several decades since Kelly's report, little work was done on the development of such dryers. Oxley (1948) referred to the conduction heating dryer as "a very popular and successful type of dryer." The dryer, consisted of hot metal surfaces on which the grain was passed and a counter current of air removed the moisture. It had been stated that by using the hot-grain cold-air principle, if cool air stream is used, a large temperature gradient was created within the kernels, and therefore the movement of moisture within the grain was facilitated.

Hall and Hall (1961) compared the rate of corn drying by conduction and convection heating. Conduction heating and drying was performed by placing the com kernels on a 1.02 mm thick steel plate suspended above an electric hot plate; for convection heating the temperature of the forced air was the same as that of the

steel plate. It was concluded that conduction drying resulted in 10.2-16.5 percent saving in drying time for heating medium temperatures of 109-62 °C.

Finney *et al.* (1963) studied conduction drying of shelled corn. The effect of air flow rates on drying time was investigated. It had been observed that the overall thermal efficiency up to 70 percent could be achieved. While it had made provisions to minimize heat loss to the ambient environment, loss of heat in the exhaust air was also inevitable.

Chancellor (1968) proposed a grain dryer using conducted heat. The dryer consisted of a metal plate heated by straw. A blade was used for stirring the grain to prevent overheating by contacting the surface for long periods of time.

Javeregowda *et al.* (1989) studied the Tomato cv. *Pusa Ruby* seeds, having an initial moisture content of 40%, in the sun (26 °C), sun and shade (24 °C), shade (22 °C), and by mechanical drying at 35, 40, 45, 50 or 55°C . A constant air flow of 3 m³min⁻¹ and a seed bed depth of 2.5 cm was maintained during mechanical drying. Seeds were dried to constant weight and then assessed for moisture content; germination and vigour index. Tomato seeds could be dried to a final moisture content of 9% in 8 h at 40 °C while retaining high % germination (90%) and vigour index (506) over the traditional methods, drying in the sun and shade produced the highest germination (94%) and vigour index (527). However, by this method the final moisture content of 8.5% was only reached after 30 h.

Doijode (1993) dried seeds of onion cv. *Nasik Red* by desiccation with silica gel (for 8 days), in sun (6 h), in shade (15 days), in an oven (40 °C for 4 h), by forced hot air (30 min), by infrared radiation (24 h) or by vacuum-drying (32 °C for 4 h). These methods reduced moisture content from 10.2 to 6.5-7.0%. Viability was maintained for longest by drying with silica gel or infrared radiation (17 and 19% germination, respectively, after 27 months of storage). Control seeds (undried, stored in paper bags) showed 92% germination after 6 months in storage, but had lost all viability after 18 months. Seedling vigour, in terms of seedling length, was highest after drying with silica gel.

Cheng *et al.* (2001) studied the effects of aging-resistance and free radical scavenging in onion seeds dried to moisture contents (MC) between 1.21% and 7.08%. The results showed that ultra-dried seeds within certain MC limits showed no deterioration in seed vigour. Furthermore, ultra-dried seeds had significantly

enhanced aging-resistant capabilities under accelerated aging conditions (50°C, 45 days). The critical MC for onion seeds was about 3%. During ultra-drying of onion seeds, the level of free radicals increased, but it decreased before imbibitions due to the scavenging action on free radicals. The activities of the antioxidant enzymes, catalase and superoxide dismutase, were preserved during storage in an ultra-dry state.

2.2. Sun Drying

Harrington (1960) reported that direct sunlight was harmful to seed viability due to ultraviolet radiation. It concluded that sun drying should be replaced with shade drying or artificial drying for higher seed quality.

Singh *et al.* (1985) observed significant reduction in germination in tomato seeds when it were dried at 12 noon in sun and shade, whereas early and late drying was found ideal for achieving quality seed in terms of high per cent seed germination. It was observed that drying of tomato seeds in sun had deleterious effect on germination than shade drying. Further it was opined that tomato seeds after extraction should not be dried at high temperature and preferably seeds should be dried during early or late hours of the day so that gradual drying could be accomplished without affecting seed germination.

Javaregowda *et al.* (1989) found that when tomato seed Cv. *Pusa Ruby* dried at 40°C and 45°C drying air temperature was critical and beyond which germination reduced drastically. Further, it was observed that sun and shade drying recorded higher germination (94%) and vigour index (527) followed by mechanical drying at 35°C temperature which recorded germination (91 %) and vigour index (490).

Javaregowda *et al.* (1990) concluded that drying of tomato seeds under combined sun and shade (24°C temperature) resulted in highest per cent germination of 94 and 90 in laboratory and field conditions, respectively. It revealed that tomato seed could be dried at 35°C or 45°C temperature without much affecting germination level. However, higher temperature (50°C and 55°C) drying depicted reduction of germination to 70 and 64 per cent, respectively.

Prasad and Tripathi (1999) studied sugarcane true seed (fluff) of five cultivars packed in perforated paper bags and dried in a dehumidifier-drying chamber at 35 °C for 12, 24, 36, 48, 60, 72 or 84 h, or sun-dried for three days, or left undried

(controls), and tested for germination. The fluff dried for 48h recorded the highest germination. The moisture content of the fluff was safely reduced to 9% from 14%. Drying the fluff in a dehumidifier-drying chamber was considered to be safe and better in terms of seed quality than sun drying.

2.3. Mechanical drying

Harrington (1972) found that if the moisture reduction progressed too slowly, then it favored invasion of fungal pathogens. It also resulted to injury of seed coat in form cracking of endosperm or cotyledons causing reduction in germination. Similar observations were also made by Kozlowaski (1972) in case of rapid drying of seed at high temperatures. However, for most of the vegetable seeds, 35-40°C temperature was only found safe.

Philpot (1976) explained the seed drying as evaporation of moisture from surface and movement of moisture from organs to the surface. If evaporation from seed surface occurs rapidly, extreme moisture stress could damage the embryo, even.

Magalhes and Groth (1992) observed that seeds of *B. humidicola* dried in the shade on asphalt and concrete had the highest germination level up to 60 and 62%, respectively and vigour 63 and 61% after 12 months, followed by those dried in rotary driers in the sun or the shade (56 and 55% germination and 53 and 56% vigour), and the undried control (52% for both germination and vigour).

Zode (1997) stated that the maximum temperature at the drying surface was 50-60 °C in sun-dried pods and 38-40 °C in shade-dried pods and sun drying required 4 days, whereas shade drying required more than 8 days for drying pods to kernel moisture content below 9%. Drying in sun at temperatures above 50 °C decreased seed viability. Seed germination after drying in sun-dried pods was 13 and 56%, respectively.

Sogi *et al.* (2001) observed that it took about 7 h at 70 °C to reduce moisture content of tomato seeds from 26% to 10% (dry basis), in cabinet dryer, while it took about 1.5 h in fluidized bed system to achieve similar moisture reduction for 8 kgm⁻² tray load.

2.3 Chemical Drying

Drying, in this case, is carried out by passing ambient air over a desiccated medium or source e.g. silica gel. The desiccants absorb moisture from the air; as a

result, the air becomes dryer. When such air comes in contact with moist seed, transfer of moisture from moist seed to drying air takes place.

Khan *et al.* (1973) found that by using a granular medium localized overheating of the product could be prevented while conductive heat transfers. At the same time, some other researchers also reported on grain drying by mixing with heated granular media (Iengar *et al.*, 1971; Akpaetok, 1973; Raghavan, 1973; Lapp and Manchur, 1974) were found efficient.

While researchers agree that using heated granular media enhances heat transfer, it seems to be less accord in employing the right stuff to achieve an optimum drying result. Therefore, researchers have experimented with a variety of solid materials as the medium for heat and mass transfer.

The choice of granular medium for heating had been as varied as the material being heated (dried) in different geographical regions. Raghavan and Harper (1974) used salt for drying. Mittal *et al.* (1985) used steel balls as the solid medium for heat transfer for drying wheat. Aguilera *et al.* (1982) employed heated ceramic beads for roasting navy beans. Arboleda *et al.* (1973) used sand for drying rice. The most commonly used medium reported is sand (Sibley and Raghavan, 1985; Lapp *et al.*, 1977; Akpaetok, 1973; Khan *et al.*, 1973; Iengar *et al.*, 1971).

Sibley and Raghavan (1985) reviewed the parameters affecting grain drying when mixed with a heated bed of granular medium. It was observed that the amount of moisture removed depended on the type of grain, initial moisture content, medium-to- grain mass ratio, medium temperature and the duration of mixing (residence time).

Danziger *et al.* (1972) studied the use of silica gel for corn drying. It was observed that the ratio of 1:3 (silica gel : corn) was effective in reducing moisture content to 10.3 % within 24h for corn of initial moisture content of 24.7 (w.b). Graham *et al.* (1983) indicated that with 1:1 initial grain mass to initial Betonite mass, the moisture content of corn dropped from 30 percent (w.b) to 17.5 percent (w.b) in 24 h.

Sturton *et al.* (1983) and Graham *et al.* (1983) reported the use of Betonite desiccant for grain drying as an efficient method. But due to its low adsorption capacity, a large amount was found its limitation.

It is observed from the literature, as above, that the major portion of moisture from grain is removed in periods longer than 24 h by desiccants like Silica gel and Betonite. Therefore, they are not optimal media for practical drying of agricultural products.

Flanigan (1984) reported that the water adsorption capacity of silica gel dropped from 25 percent at about 15°C to almost nil when the temperature increased to 65°C. On the other hand, it was observed that molecular sieve zeolites retained water at higher temperatures. It advocated the use of zeolites for drying.

Zhang and Tao (1988) studied various seed of different moisture content of 4 *Phaseolus vulgaris* and 2 maize cultivars (both species large-seeded), one rice and 4 cucumber cultivars (medium) and 2 Chinese cabbage cultivars (small-seeded) using silica gel. Seed moisture content was lowered to 3-7% within a month using the silica gel, even in one maize cultivar whose initial moisture content was 60.5%. No adverse effects on germination and seed vigour were observed after drying and storing for 6 months at 10-20°C or 40°C in sealed, laminated aluminum bags.

Lin and Zheng (1993) used silica gel as a desiccant, the moisture content of sorghum seeds, it decreased from 13.1 to 3.8 at 30 °C in 17 d, while at 20-25 °C it took 40 d. In both seed lots the germination rates were very similar. Storability was significantly increased.

Xiorong *et al.* (1998) conducted a study to compare the efficiency of two methods commonly used for seed moisture conditioning for storage in seed gene banks: vacuum freeze drying and drying over desiccants. Efficiency was evaluated in terms of the water contents that could be obtained, the speed at which seed could be dried, the incidence of damage to seed during drying and the cost. Seed of eight crop species (barley, japonica rice, oats, kenaf (*Hibiscus cannabinus*), sesame, rape, amaranthus tricolor and *Phaseolus calcaratus* (*Vigna umbellata*) were dried from ambient conditions of about 20°C and 80% RH using a freeze-drier or silica gel as a desiccant. Drying to low water contents had no measurable effect on germination percentage. Drying rates using silica gel or a freeze-drier were comparable, but lower water contents could be obtained using silica gel; also, silica gel was readily available and the daily rental fees made the cost of freeze drying prohibitive, thus drying using silica gel was found viable method.

Zheng *et al.* (2001) investigated the effect of ultra-drying on seeds of Chinese cabbage, leek, tomato, radish, aubergine and cucumber to reduce moisture content to 3.0-5.5% by heat drying at 45°C, silica gel drying at 25°C, low temperature drying at 15°C and freeze drying at -20°C. After 10 years, the seeds preserved in sealed aluminum bags at room temperature (20-35°C) with moisture content of 7-10% had lost their total germination capacity, except for aubergines. All silica gel, freeze and heat dried seed had high germination capacity that was similar to the original viability. These 3 drying methods could be safely used to ultra dry all vegetable seed, studied. Seed viability was not affected by drying temperature. Seed moisture content of 2.5-4.5% at ambient temperature was recommended for the long-term storage of all the vegetables studied. The ultra-dried seeds could be stored safely at room temperature for 10 years.

Hu *et al.* (2002) subjected maize seed to ultra drying treatment before storage using two approaches, silica gel drying and heat drying at high temperatures, and then stored for seven years under room temperature and airtight conditions. Results of seed germination and superoxide dismutase activities showed that viability and vigour of maize seed which had their moisture content lowered to 4.05% by silica gel drying were highest, while those with moisture content higher than 7.49% were non-viable. Maize seed heat-dried at high temperature generally had lower viability and vigour. Germination percentage of such seed was suddenly reduced to zero when moisture content was below 5.79% and hence were not suitable for ultra dry storage. In this case, watermelon (*Citrullus lanatus*) seed were only dried with Silica gel before storage in this experiment and then stored under the same conditions as maize seed. Watermelon seed that had the highest viability and vigour were those that had a moisture content of 3.73% and their germination percentage reached 71.5%. Both seed viability and vigour were significantly reduced when moisture content was either lower or higher than 3.73%. It is suggested that desiccation by silica gel drying is beneficial to long-term storage of maize and watermelon seed within a certain period, but over drying treatment was favorably applied to maize and watermelon seed.

Hong *et al.* (2005) studied the effect of hermetic storage of seed of carrot, groundnut, lettuce, oilseed rape and onion in laminated aluminum foil packets in four environments (dry or ultra-dry moisture contents combined factorially with

temperatures of 20°C or -20°C), replicated at several sites. After ten years of hermetic storage, seed moisture content, equilibrium relative humidity, viability (assessed by ability to germinate normally in standard germination tests) and vigour were determined. After a decade, the change in seed moisture content of samples stored at -20°C was small or nil. Except for groundnut and lettuce (where loss in viability was about 8 and 3%, respectively), no loss in viability was detected after 10 years' hermetic storage at -20°C. In all cases, there was no difference in seed survival between moisture contents at this temperature ($P>0.25$). Comparison of seed vigour (root length and rate of germination) also confirmed that drying to moisture contents in equilibrium with 10-12% r.h. had no detrimental effect to longevity when stored at -20°C: the only significant ($P<0.05$) differences detected were slightly greater root lengths for ultra-dry storage of four of the six seed lots. Seed moisture content had increased after a decade at 20°C (generally to the level in equilibrium with ambient relative humidity).

Zeng *et al.* (2006) investigated the ultra drying of seed of *S. splendens* using silica gel to reduce the moisture content from 8.9 to 4.5, 3.4, 3.0, 2.7 and 2.2%. Significant changes in physiological parameters and vigour of *S. splendens* were detected when the seeds were re-moistened after being stored at room temperature and 5°C for 13 months. The germination rate, germination potential, and germination index of seed subjected to ultra-drying were higher than those of the control. Compared with the control, the peak time of germination occurred 1-2 days earlier, the electrical conductivity was lower, and the dehydrase activity was greater in ultra dried seeds. The germination rate, germination potential, and germination index of ultra dried seeds did not significantly differ between storage at 5°C and storage at room temperature for 13 months. When stored at 5°C for 13 months, the parameters of ultra dried seeds varied from those of the control seeds. The effects of ultra drying were markedly affected by the seed moisture content. For seeds of 3.4-4.5% moisture content, the germination rate, germination potential and germination index were increased, whereas the electrical conductivity was reduced. For seeds with moisture contents of 3.0, 2.7 and 2.2%, the germination rate, germination potential, and germination index decreased, whereas the electrical conductivity increased. The dehydrase activity significantly declined. The results suggested the suitability of ultra drying treatment for seed storage.

Dhaliwal *et al.* (2009) developed a dryer to dry seed at safe temperatures that used a silica-gel bed and an electric heater. The air was re-circulated in the drier for energy conservation. The compact desiccant drier was tested with brinjal and carrot seeds. Drying temperature was 40°C. Carrot seed were dried from an initial moisture content of 8.8 to 4.9% (wb) while farm fresh brinjal seed were dried to a final moisture content of 5.7% (wb). Silica-gel was regenerated with hot air supplied by an electric heater at 90°C.

Jiang *et al.* (2009) carried out experiments to study the effects of ultra drying treatment on vigour and anti-oxidase activity of *C. intybus* seed. Seed of *C. intybus* were ultra dried with silica gel to reduce the moisture content to concentrations of 8.45%, 5.17%, 3.64%, 2.33%, and 1.69%. Seeds were then sealed in aluminum foil bags and stored in a calorstat at 50°C for 10 d. The seed vigor and anti-oxidase activities were assessed after they were re-moistened. There were no significant changes of seed physiological parameters under ultra drying or non-ultra drying treatments before temperature treatment. Seed germination rate and vigor index of *C. intybus* seeds were higher than those of the control under conditions of ultra drying after temperature treatment while the electric conductivity and MDA content were lower than those of the control. The activity of dehydrogenase, peroxidase and hydrogen peroxidase were higher than those of the control. For ultra drying of seeds, 2.33% moisture content was better than other moisture contents for storage effectiveness. The results demonstrated that with an appropriate ultra drying treatment, *C. intybus* seed could maintain robust vitality with enhanced storage effectiveness and thus provide a basis for suitable storage of *C. intybus* seed.

Chen *et al.* (2011) investigated the effect of ultra-dry treatment on seed storage of *Hedysarum laeve*. The seed moisture contents were reduced from 7.900% to 1.829%, 2.921%, 3.460%, or to 4.645% by silica gel, and were then stored at -4°C, at 4°C, at room temperature, or at 45°C. They were tested for physiological and chemical indexes after 12 months. Appropriate ultra-dry treatment enhanced storage effectiveness, increased membrane permeable and activity of SOD, POD, and CAT, but reduced the MDA content of *H. laeve* seeds. The optimal moisture content for ultra-dry storage was 3.460%. Ultra-drying at room temperature resulted in the same storage effects as treatment at low temperature. Appropriate ultra-dry treatment was therefore an effective conservation measure for *H. laeve* germplasm resources.

Despite the better performance of desiccants for drying, their use is limited because they lose the adsorption capacity with repeated use.

Hay *et al.* (2012) carried out four experiments using zeolite Drying Beads to dry freshly harvested rice seeds to low moisture content. The beads were mixed with 120 g of seeds in different ratios (between 0 and 3 beads-to-seed, by weight), sealed inside moisture-proof bags or heat-sealed laminated aluminum foil packets and placed in temperature controlled environments for drying and/or storage. The first experiment confirmed that the bead drying system was faster. The final moisture content of the seed was found depended on the seed bead ratio and, to some extent, on the temperature, with slightly more drying at 30°C compared with 15 or 5°C. When seeds were stored with the beads at either 5 or -20°C, seed continued to dry. In the first two experiments, insufficient beads (bead-to-seed ratios of 0.97 and 1.06) were used to reach the target moisture content of 6.1%. The lowest moisture content reached was 4.2%, when the quantity of beads was three-times that of seeds. Germination was similar for seed stored for 371 days at 5 °C either with or without the beads after the same initial drying treatment. There was lower germination of seed dried at low temperature and then stored at -20 °C; however, this was attributed to dormancy. Whilst the water uptake isotherms confirmed the high capacity of the beads compared with silica gel, particularly at low relative humidity, the beads do not work to full capacity in a bead-seed system and the adsorption properties appeared to change.

Zeolites are a group of minerals characterized by reversible loss and gain of water without significant structural deformation (Mumpton, 1984). Synthetic Zeolites are also referred to as molecular sieves. Zeolites are adsorbent and all pores are filled at very low relative pressure of adsorbate. Zeolites can be used in various purposes. Mumpton (1978) discussed in detail the various applications of zeolites ranging from oil-spill cleanup to polishing agent in fluoride containing toothpaste. The application of these zeolites in the chemical industry includes drying air and other gases. In the agricultural field, the use of zeolite is reported for waste treatment.

CHAPTER 3

MATERIALS AND METHODS

Seed is living entity and low moisture content seed have been found higher longevity. Method of reducing moisture content is critical in general and becomes most important for high value low volume seed (vegetable seed) in particular as they are very sensitive. Furthermore, poor storability of these seeds is common in hot and humid climatic conditions. Popular drying method *i.e.* hot air system adversely affects the seed quality. In light of these facts, a nascent method of drying *viz.* beads drying was has investigated for onion and tomato seed drying. The details of the materials and equipment methods used for present study are described under the following broad heads:

3.1. Raw Material

3.2. Equipment

3.3. Physical dimensions of Seeds and Beads

3.4. Regeneration of Beads

3.5. Experimental Design

3.6. Drying Experiments

3.7. Seed Quality Analysis

3.8. Optimization of Independent Variable

3.1. Raw Material

Tomato seed cv. *Pusa Ruby* and Onion seed cv. *Nasik Dark Red* were procured from the local market as per requirement and stored in dry shaded place and were used for the present study. Zeolite beads for drying were procured from Ambala Associates, Ambala which was imported from RR Group, Taiwan.

The studies on Beads drying system for tomato and onion seeds were carried out in Division of Agricultural Engineering and Division of Seed Science and Technology, Indian Agricultural Research Institute; New Delhi during 2012-2013.

3.2. Equipment

Various equipment used during the experiment are listed in Table 3.1.

Table 3.1. List of equipment/instruments used and their specifications

Equipment/ Instruments	Make
Microwave Oven	LG 800-140 Wattage
Hot Air Oven	Wisvo
Desiccators	Aristo
Digital Vernier Caliper	Mitutoyo
Thermometer	Raj
Portable Mini Data Logger	RR Group
Air Tight Containers	Aristo

3.2.1. Microwave Oven

Domestic microwave (fig. 3.1) oven was used. A microwave oven is an appliance that heats a material by bombarding it with electromagnetic radiation in the microwave spectrum causing polarized molecules in the material, like water, to rotate and build up thermal energy in a process known as dielectric heating. Microwave ovens heat product quickly, uniformly and efficiently because excitation is fairly uniform in the outer 25–38 mm of; the product is more evenly heated throughout (except in thick, dense objects) than generally occurs in other heating techniques. The microwave oven



Fig. 3.1. Microwave Oven



Fig. 3.2. Hot Air Oven



Fig. 3.3. Digital Vernier Caliper



Fig. 3.4. Portable Data Logger

used in the present study was of LG make capable of working on 220 V, 50-60 Hz, AC power source. The wattage was adjustable in the range of 140 to 800.

3.2.2. Hot Air Oven

Hot air oven Wisvo make (fig.3.2) was used for regeneration of beads. It was working on 220 V, 50 Hz, AC power supply. Its working temperature was in the range of 50 - 300 °C. In order get constant temperature inside the oven, a thermostat was equipped with heating element in series. Set and present temperature was displayed by LED display. It had double walled insulated rigid body. A circulation fan was installed in the oven to maintain uniform inside temperature. The provision of time control was also there. To keep the material inside there were removable aluminium trays arraigned vertically.

3.2.3. Vernier Caliper

The digital Vernier caliper of least count 0.01 mm (fig. 3.3) was used to determine seed and bead leaner parameters. The measurement was done with using following equation:

$$TR = MSR + (VSR \times LC)$$

Where,

TR = Total reading; mm

MSR = Main scale reading; mm

VSR = Vernier scale reading; mm

LC = Least count (0.01 mm)

3.2.4. Portable Mini Data Logger

A portable mini data logger (fig. 3.4) was used for recording temperature and humidity of container where drying was experimented with beads. It had feature of setting the recording parameters i.e. time interval of measurable parameters. It was compact and battery operated. It contained data storage chip which can store 75000 data point. The logger had feature that the recorded data could be exported to external computer through EasyLog software in form of Microsoft Excel Sheet as

well as chart form. Data logger was set using EasyLog software. It had a provision for setting the interval of recording data. It also had the facility for setting a point of time start of set parameters (temperature and relative humidity). These setting could be done by hooking the data logger to personal computer and using EasyLog software. Recorded data was downloaded to personal computer by connecting the logger through USB port and its software.

3.2.5. Containers

The containers were of Aristo make of 1 litre capacity. It was made of thick PEP material and had a silicon gasket. It was airtight and was thus able to isolate the sample from ambient atmosphere

3.3. Physical Dimensions of Seeds and Beads

To determine average seed size, 100 seeds of tomato and onion each were randomly selected from lot and their three linear dimensions namely, length (L), width (W) and thickness (T) were measured using a digital vernier caliper (fig.3.3). The arithmetic mean diameter (Da) and geometric mean diameter (Dg) of the seed were calculated by using the following relationships (Mohsenin, 1986):

$$D_a = \frac{L+W+T}{3}$$

$$D_g = (LWT)^{\frac{1}{3}}$$

Where,

L = length; mm

W= width; mm

T = thickness; mm

Surface area (S) was calculated using the following equation (Jain and Bal, 1997):

$$S = \frac{\pi BL^2}{(2L - B)}$$

$$B = \sqrt{WT}$$

Beads surface area was calculated using following equation:

$$S = \pi D^2$$

Where,

D = average diameter of bead; mm

3.4. Regeneration of Beads

Regeneration of Beads implies the reactivation of beads so that they can be re-used for further drying. External heating causes the beads to lose adsorbed moisture. In the present study the beads were regenerated using Hot Air Oven and Microwave Oven.

3.4.1. Hot air oven regeneration

The weighed beads were kept in desiccators containing a layer water of depth 5 cm without touching the water. The desiccators with water and bead were subjected to constant temperature of 35 °C with closed lead condition for saturating the beads. At regular interval of 2 h beads were weighed up to reaching constant weight. This state of beads was considered as maximum water adsorption state. The conditioned beads were used for optimization of regeneration parameters. The conditioned beads of 250 g were exposed to temperature of 150, 200 and 250 °C and for 1, 2, 3 and 4 h in hot air oven in three replications. After elapsing the duration at specified temperature, beads were weighed on electronic balance of sensitivity of 0.001 g. The percentage loss of weight was calculated to evaluate regeneration process.

3.4.2. Microwave oven regeneration

The beads were fully hydrated using desiccators filled with plain water prior to regeneration in the same manner as mentioned in section 3.4.1. A Microwave Oven of LG make with 140 to 800 Wattage was used. The beads after attaining full saturation level were kept in domestic microwave at 800W, 640W and 480W for 10,

15 and 20 minutes. After elapsing the duration at specified temperature beads were weighed on electronic balance of sensitivity of 0.001 g. The percentage loss of weight was calculated to evaluate regeneration process. The energy consumption was recorded using an energy meter attached to the circuit.

3.5. Experimental Design

The Central Composite Rotatable Design (CCRD) was used for three independent variables at five levels (Table 3.2). Response Surface Methodology (RSM) was used for analyzing the data as it helps to reduce the number of experiments without affecting the accuracy of results and depicts interactive effects of variables on the responses (Myers, 1971). The experimental design layout is presented in Table 3.3.

Table 3.2: Process variables and their levels

Process Variables	Coded Level					
	Code	-1.682	-1	0	1	1.682
		Actual Levels				
Seed- Bead Ratio	X ₁	1:0.33	1:0.5	1:0.75	1:1	1:1.17
Residence Time, hr	X ₂	1.3	4	8	12	14.7
Initial Moisture content, %	X ₃	8.64	10	12	14	15.36

Table 3.3: Experimental Layout

Expt. No	Coded Levels			Real Levels		
	X ₁	X ₂	X ₃	S:B ratio	Res time	IMC %
1	0	0	0	1:0.75	8	12
2	0	0	0	1:0.75	8	12
3	0	-1.68	0	1:0.75	1.3	12

4	0	1.68	0	1:0.75	14.7	12
5	1	-1	-1	1:1	4	10
6	1	1	1	1:1	12	14
7	0	0	0	1:0.75	8	12
8	-1	-1	1	1:0.5	4	14
9	1	1	-1	1:1	12	10
10	-1	1	1	1:0.5	12	14
11	-1	1	-1	1:0.5	12	10
12	0	0	-1.68	1:0.75	8	8.64
13	0	0	0	1:0.75	8	12
14	1	-1	1	1:1	4	14
15	0	0	0	1:0.75	8	12
16	-1.68	0	0	1:0.33	8	12
17	0	0	1.68	1:0.75	8	15.36
18	0	0	0	1:0.75	8	12
19	-1	-1	-1	1:0.5	4	10
20	1.68	0	0	1:1.17	8	12

3.6. Drying Experiments

The actual experiments were conducted after attaining the moisture contents as required by the experimental design. The seeds were then mixed with beads at corresponding ratios with the corresponding initial moisture content into the air tight containers. These containers were kept at room temperature for the corresponding

residence time of the experiment. The seeds were separated from the beads after drying using perforated sieve (fig 3.4). The moisture contents of the dried seeds were determined by standard oven method.

3.6.1. Moisture Content Determination

Seed moisture content is one of the most important factor influencing seed quality and storability. Therefore, its estimation during seed quality determination is important. Seed moisture content can be expressed either on wet weight basis or on dry weight basis. Seed moisture content can be determined either by air oven or moisture meter. However, in this study air oven method was used.

Moisture content was determined using standard hot air oven method (ISTA, 1999). Two to five gram sample of seeds was taken in glass viols dried for 1 hour at 130 °C in case of tomato seeds and for 17 hours at 103 °C in case of onion seeds. After drying moisture content of sample was calculated using following equation:

$$M.C = \frac{(M_2 - M_3) \times 100}{M_1}$$

Where, M.C. = moisture content, % (w .b.)

M_1 = Initial weight of the sample, g

M_2 = Weight of (sample +viol) before drying, g

M_3 = Weight of (sample + viol) after drying, g

3.7. Seed Quality Analysis

The dried seeds were evaluated for final moisture content, germination percentage, seed vigour index I and seed vigour index II analysis to explore effect of drying on seed quality.

3.7.1. Germination Percentage

It is a laboratory test under which the emergence and development from the seed embryo of essential structures occurs and in turn indicates the ability to develop

a normal plant under favourable conditions. The ultimate objective of seed germination testing is to obtain information with respect to the planting value of the seed and to provide result which could be used to compare the value of different seed lots. The test was conducted according to ISTA rules (1985). Three replicates of 200 seeds were placed in petri dish containing wet filter paper. In each petri dish 50 seeds were placed at equal distance. The germinator was set to operate at 25 °C and above 80% RH for 14 days and 12 days for tomato and onion seed, respectively (McDonald and Copeland, 1999). After elapsing the specified duration with respect to crop (tomato and onion), number of normal seedlings, hard seed and abnormal seedlings were recorded. Seedlings were counted as normal, which had well developed root system including a primary root, intact plumule with well-developed leaf. Those seeds which did not absorb water were classified as hard seeds. Seedlings which did not have primary root system or weak or unbalanced development of the essential structures such as spirally twisted or stunted plumules, swollen shoots or stunted roots or decay or diseased of any essential structures were recorded under abnormal seedling count. The germination per cent was expressed on the basis of normal seedlings.

3.7.2. Seed Vigour Index

Seed vigour is an important quality parameter to supplement germination and viability tests to gain insight into the performance of a seed lot. It was calculated by determining the germination percentage and seedling length of the same seed lot. Fifty seeds each in three replications were germinated on wet filter papers in petri dishes as prescribed for the crop specie in germination test. While evaluating the number of normal seedlings at the time of final count the seedling length of 10 randomly selected seedlings were measured. Seed vigour index was calculated by multiplying germination (%) and average seedling length (mm). This vigour index was termed as Vigour Index I. The seed lot showing the higher seed vigour index is considered to be more vigorous (Abdul-Baki and Anderson, 1973).

Seed vigour index II was determined by using the dry weight of seedlings. For dry weight determination, ten normal seedlings were selected randomly from germination test sample. These seedlings were dried oven at 100 °C temperature for 24 hours. The dry seedling weights were recorded. The dry weight of 10 randomly

selected normal seedlings was determined using electronic balance. The dry weight in mg was multiplied with corresponding germination percentage. This number obtained was termed as Vigour Index II.

3.8. Statistical Analysis

Full second order model was fitted in various responses and independent variables using least square regression analysis. Data analysis and optimization was done by using Design Expert 8.0.7.1 software. Response Surface Methodology was used in this study. Effect of independent variables on the responses was interpreted using the models. 3D response surface plots were drawn with the help of Design Expert to get the idea about the influence independent variables.

CHAPTER IV

RESEARCH PAPER I

Optimization of Drying Protocol for Beads Drying System

4.1. Abstract

Water status is important for all the living processes. In the living tissues, water serves as a fluid medium and stabilizes the structures of macromolecules. The moisture content is frequently higher (ranging 15-18%) at the time of harvest than the optimum to obtain the best potential life of seed. Hence, it is necessary to reduce the moisture content before storing the seed. Drying seeds and maintaining low seed moisture content is critical in hot and humid climatic conditions. There are various drying methods; ranging from sun drying to highly complex mechanical drying system. Zeolite beads which are inert adsorbent materials were used for drying in this study. Response Surface Methodology (RSM) was employed to optimize the parameters of drying in central composite experimental design. The seed of tomato cv. *Pusa Ruby* and onion cv. *Nasik Dark Red* with initial moisture content of 8.6 to 15.4% dry weight basis (d.b), were dried at five levels of residence time(1.3, 4, 8, 12, 14.7 h) and five levels of seed bead ratio(1:0.33, 1:0.5, 1:0.75, 1:1, 1:1.17).

The data from experiments was analyzed statistically using Design Expert 8.0.7.1 software and the response functions were developed using multiple regression analysis and second order models were fitted for each response. Models were found to be significant for all the response variables namely, Final moisture content (FMC), Germination percentage (GP), vigour index-I (VI-I) and vigour index-II (VI-II) for tomato seed. In case of onion, models were observed to be significant for FMC and GP only. The optimum values of process variables were found to be 1:0.5, 10.8 hours and 11.84 percent, seed bead ratio, residence time and initial moisture content, respectively for tomato seed. Seed bead ratio, residence time and initial moisture content of 1:0.62, 6.52 and 13.62, respectively were found optimum for onion seed.

Keywords: Drying, Zeolite beads, response surface methodology, regeneration

4.2. Introduction

Water status is therefore most important to fix all the living process. In the living tissues, water serves as a fluid medium and stabilizes the structure of macromolecules. High moisture content of seed is congenial for activity and growth of macromolecules, which can diminish or destroy the seed quality rapidly. Moisture levels affect physical status of seed. High moisture content makes seed soft, which is liable to mechanical damage. It is necessary to harvest at earliest after attaining the physiological maturity. At physiological maturity the stabilization of dry matter and translocation to the seed ends and at this juncture seed express the maximum germination and vigor potential (Marcos- Filho *et al.*, 1994). However, moisture level in seed is at higher which may be detrimental. It establishes importance of drying in seed production system. Drying permits harvesting the grain as soon as it is ripen and mature to avoid field losses and conditions to safe storage (Henderson and Perry, 1976). The drying process was found one of the major effective tools for preservation agricultural seed industry (Crapiste and Rotstein, 1997). Among artificial drying system hot air system is common. The important factors affecting the drying process are drying air temperature, relative humidity and velocity, initial seed moisture content (Amer *et al.*, 2003). Other factors like type of grain, variety, drying method, dryer type and efficiency of the dryer can also affect the processes considerably as well as quality of dried seed. Faster drying are desirable but may lead to undesirable grain cracking. Seed quality of high value low volume seed is very sensitive with drying temperature at higher level (Javaregowda *et al.*, 1990). Among high value low volume seed, tomato and onion seeds are critical with hot air seed drying as exposure to high temperature induces heat injury to seed. In turn, reduces germination, vigor and/or shelf life considerably. Apart from hot air system, vacuum drying, microwave drying and refrigeration drying could be utilized. However, its high initial cost is limiting factor for its use. Use of desiccants for drying the material is in practice for small lots. Silica gel, Betonite and some salts (calcium sulfate, calcium chloride, sodium chloride) have been experimented for drying of seed. It has been found effective in reducing moisture content of seed (Xiorong *et al.*, 1998; Zheng *et al.*, 2001; Hu *et al.*, 2002; Zeng *et al.*, 2006). But normally desiccant drying is very slow process. Although silica gel can be regenerated by heating at a lower temperature, there is loss of water holding

capacity of silica gel due to polymerization after repeated heating. It all, this method makes a non-viable option for bulk handling. Recently, zeolite beads (desiccant) has been developed which can be used as drying desiccant (Asbrouck and Taridno, 2009). Silica gel has a lower affinity for water than drying bead at the lower humidity level. Also, there is no loss of water holding capacity of drying beads after repeated regeneration process. The beads have an extremely high capacity to absorb water, even at very low air humidity, making them optimal drying material. The adsorption process is fully reversible and of purely physical nature. The beads can be regenerated indefinitely by heating to elevated temperature. However, very little information is available for the process parameters of beads drying. It is imperative to optimize process parameters for effective and efficient application.

Response surface methodology (RSM) is a statistical procedure frequently used for a wide range of optimization studies (Madamba, 2002). RSM allows us to find the optimal working conditions by combining a small number of variables, resulting in fewer experiments (Mullen and Ennis, 1979). RSM was employed in optimizing drying operations and techniques (Barrozo *et al.*, 2006; Madamba and Liboon, 2001; Madamba, 2002; Madamba and Lopez, 2002; Zhang *et al.*, 2003). It uses quantitative data from an appropriate experimental design to determine and simultaneously solve multivariate problems. The equations describe the effect of the test variables on the responses, determine interrelationships among test variables and represent the combined effects of all test variables in the response. This approach enables us to make efficient exploration of a process or system (Madamba, 2002).

In light of above facts, the present study was undertaken to optimize the process variables of bead drying for high value low volume seed, considering onion and tomato seed as test seed lot. As these two seed have high economic importance as well as critical for conventional drying system.

4.3. Materials and Methods

The materials used and the methods employed in the study are discussed in the following heads:

4.3.1. Sample preparation

The popular varieties of tomato and onion seed, cv. *Pusa Ruby* and *Nasik*

Dark Red, respectively were procured from the local market. The moisture content of tomato and onion seed was 8.7% and 11.2% (db), respectively. The seed lots were conditioned to required moisture content levels (9, 10, 12, 14 and 15.5 %) through hydration in desiccators.

4.3.2. Seed Moisture Content Determination

Moisture content was determined using standard hot air oven method (ISTA, 1999). Two to five gram sample of seeds was taken in glass vials dried for 1 hour at 130 °C in case of tomato seeds and for 17 hours at 103 °C in case of onion seed. After drying moisture content of sample was calculated using following equation:

$$M.C = \frac{(M_2 - M_3) \times 100}{M_1}$$

Where,

M.C. = moisture content, % (w .b.)

M₁ = Initial weight of the sample, g

M₂ = Weight of (sample + viol) before drying, g

M₃ = Weight of (sample + viol) after drying, g

4.4 Drying Methodology

Drying experiments were carried out in air tight containers at room temperature. Seed and beads were mixed in the specific ratio (1:0.33, 1:0.5, 1:0.75, 1:1, 1:1.17) as decided in experimental design. After elapsing specified duration as per experimental design, seed and beads were separated using sieve. Final moisture content of separated seed was determined using standard hot oven method.

4.5. Seed Quality Analysis

The dried seed lots were subjected to seed quality analysis. The important seed quality parameter namely germination percentage, vigour index-I and vigour index-II were undertaken for quality analysis.

4.5.1. Standard germination test

It is a laboratory test under which the emergence and development from the seed embryo of essential structures occurs and in turn indicates the ability to develop a normal plant under favourable conditions. The test was conducted according to ISTA rules (1985). Three replicates of 200 seeds were placed in petri dish containing wet filter paper. In each petri dish 50 seeds were placed at equal distance. The germinator was set to operate at 25 °C and above 80% RH for 14 day and 12 days for tomato and onion seed, respectively (McDonald and Copeland, 1999). After elapsing the specified duration with respect to crop (tomato and onion), number of normal seedlings, hard seed and abnormal seedlings were recorded. Seedlings were counted as normal, which had well developed root system including a primary root, intact plumule with well-developed leaf. Those seeds which did not absorb water were classified as hard seeds. Seedlings which did not have primary root system or weak or unbalanced development of the essential structures such as spirally twisted or stunted plumules, swollen shoots or stunted roots or decay or diseased of any essential structures were recorded under abnormal seedling count. The germination per cent was expressed on the basis of normal seedlings.

4.5.2. Seed vigour indices I and II

At the time of final count during germination test the length of ten randomly selected normal seedlings were measured. The vigor index I was calculated with using following formula:

$$V-II = \text{Germination percentage (\%)} \times \text{Mean seedling length(mm)}$$

Also the dry weights of ten randomly selected normal seedlings were weighed which was used to calculate vigor index-II as:

$$VI-II = \text{Germination percentage (\%)} \times \text{Mean seedling weight(mg)}$$

4.6. Experimental Design and Statistical Analysis

A central composite design can be used to evaluate the optimum drying conditions. In the following case, three mathematical functions of f_k areas summed to exist for Y_k :

$$Y_k = f_k (\text{seed bead ratio, residence time and initial moisture content})$$

A second-degree polynomial equation in the following form can be used

to approximate the function f_k .

$$Y_k = \beta_0 + \sum_{i=1}^3 \beta_i X_i + \sum_{i=1}^2 \sum_{j=i+1}^3 \beta_{ij} X_i X_j + \sum_{i=1}^3 \beta_{ii} X_i^2 \quad \dots\dots\dots 4.1$$

Where, β_0 , β_{ii} , β_{ij} are regression coefficients and X_i 's are the coded independent variables of seed bead ratio, residence time and initial moisture content while Y_k is the dependent variable or the measured response.

This experiment was carried out using the Central Composite Design (CCD) and coded as -1.682, -1, 0, +1 and +1.682. Seed of initial moisture content 8.6 to 15.6% (d.b), were dried with seed bead ratio varied from 1:0.33 to 1:0.17 for residence time ranging from 1.3 to 14.7 hour. All together, there was total 20 runs. The coding of the independent variables is presented in Table 4.1 and the experimental design in Table 4.2.

Table 4.1: Process variables and their levels

Process Variables	Coded Level					
	Code	-1.682	-1	0	1	1.682
		Actual Levels				
Seed- Bead Ratio	X_1	1:0.33	1:0.5	1:0.75	1:1	1:1.17
Residence Time, hr	X_2	1.3	4	8	12	14.7
Initial Moisture Content, %	X_3	8.64	10	12	14	15.36

Response surface regression was performed for the collected data. The analysis included fitting a full second-order response surface, analyzing the spectral properties of the fit surface and calculating the ridge of optimum response. Equations were derived by response surface regression using seed bead ratio (X_1), residence time (X_2) and initial moisture content (X_3) as independent variables while the final moisture content (FMC), germination percentage (GP), seed vigour index I (VI-I) and seed vigour index (VI-II) were all considered as responses. Using RSM, an optimum

combination of seed bead ratio, residence time and initial moisture content was determined.

Table 4.2: Experimental Layout

Expt. No	Coded Levels		
	X_1	X_2	X_3
1	0	0	0
2	0	0	0
3	0	-1.68	0
4	0	1.68	0
5	1	-1	-1
6	1	1	1
7	0	0	0
8	-1	-1	1
9	1	1	-1
10	-1	1	1
11	-1	1	-1
12	0	0	-1.68
13	0	0	0
14	1	-1	1
15	0	0	0

16	-1.68	0	0
17	0	0	1.68
18	0	0	0
19	-1	-1	-1
20	1.68	0	0

4.7. Result and Discussion

Experiments were conducted as per Central Composite Rotatable Design (CCRD). The Response Surface Methodology (RSM) was applied to the obtained experimental data using statistical package Design Expert 8.0.7.1. The estimated regression coefficients of second order polynomial models for the various responses and their statistical validity defining values are reported in Table 4.3 and 4.4. The R^2 values of all the models for final moisture content (FMC), germination percentage (GP), Vigour index-I (VI-I) and II(VI-II) were more than 80% for tomato. Similar trend was observed for onion except vigour indices. It implied that the most models developed had the capability of being used to navigate the design space and predict the response correctly. On analysing the calculated F values reflected that all the models (FMC, GP, VI-I and VI-II) developed for tomato were significant. However, only two models (FMC and GP) for onion were found significant. The values of CV were found less than 10% which established that the experiments were having reasonable accuracy and the models could be reproducible (Montgomery, 2001). The lack of fit was found insignificant for all the models irrespective of crop, excluding the model of onion vigour.

4.7.1. Final moisture content

Final moisture content is measure of drying extent. The response surface plots of final moisture content as a function of independent variables for tomato and onion are depicted in Fig. 4.1 and 4.2, respectively. The final moisture content of tomato seed was found varying in the range of 2.8 to 5.6 percent. However, it was observed in the range of 3.6 to 6.9 for onion seed.

The process variables namely, seed bead ratio, residence time and initial moisture content had found significant effect on final moisture content for onion and tomato seed. It was observed that the seed bead ratio had a negative significant (5%) effect on final moisture in case of tomato seed, while it was significant at 1% for onion seed. The decrease in final moisture content with increase in seed bead ratio may be attributed to the higher surface area available for moisture adsorption. Residence time had also shown negative significant effect ($p < 0.01$) on FMC, for both tomato and onion seed. Significant positive effect of initial moisture content of tomato ($p < 0.01$) and onion ($p < 0.05$) may be due to continued adsorption of moisture by beads.

Table 4.3. ANOVA and regression coefficients of the second order polynomial model of the various responses for tomato seeds

Predictor	Regression Coefficients			
	FMC	GP	VI I	VI II
Intercept	3.68	77.17	11372	1877.58
X_1	-0.15**	0.12	24.88	18.49
X_2	-0.65***	1.10***	298.90***	43.50***
X_3	0.63***	-1.45***	-391.16***	-53.16***
X_1X_2	-0.14	0.25	58.36	24.01
X_1X_3	-0.012	0	-0.21	-12.24
X_2X_3	-0.14	0.75	213.74	21.86
X_1^2	0.008	0.096	32.56	-10.44
X_2^2	0.097	-0.26	-82.71	-8.87
X_3^2	0.18***	0.97***	-297.67**	-35.90**
ANOVA				

R²	96.59	84.42	84.98	81.22
Model F value	31.49***	6.02***	6.29***	4.81**
CV	5.38	1.43	2.69	2.59
Lack of Fit	NS	NS	NS	NS

X₁, coded seed-bead ratio; X₂, residence time; X₃, initial moisture content; NS, non significant; *** Significant at 1 % (p < 0.01); ** Significant at 5 % (p < 0.05).

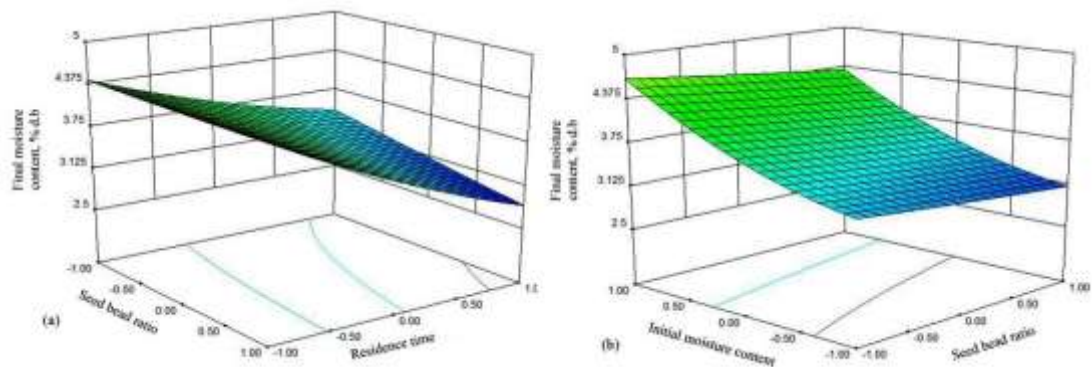


Fig. 4.1. Response surface plot for final moisture content of tomato seed as a function of (a) seed bead ratio and residence time (b) initial moisture content and seed bead ratio while other variables are at centre point

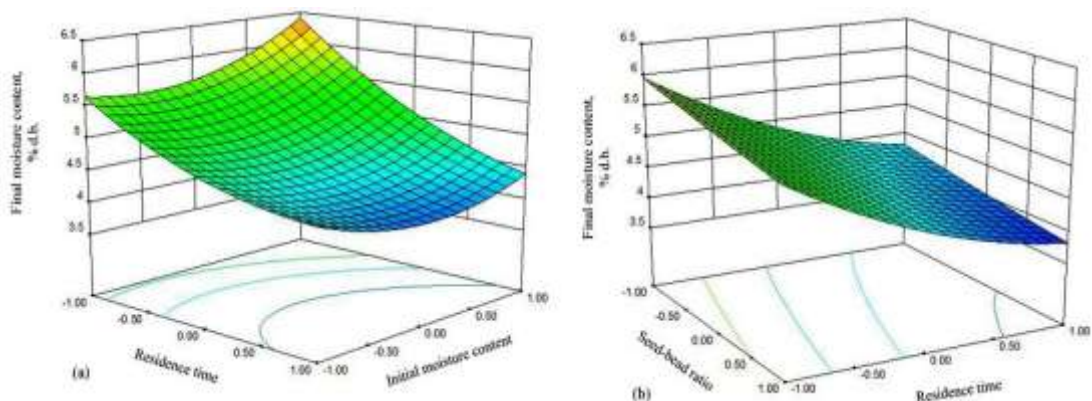


Fig. 4.2. Response surface plot for final moisture content of onion seed as a function of (a) residence time and initial moisture (b) seed bead ratio and residence time while other variables are at centre point

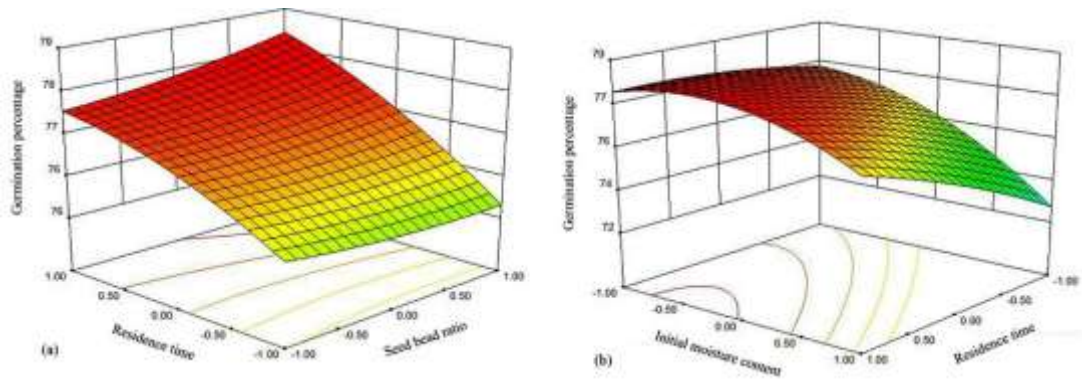


Fig. 4.3. Response surface plot for germination percentage of tomato seed as a function of (a) residence time and seed bead ratio (b) initial moisture content and residence time while other variables are at centre point

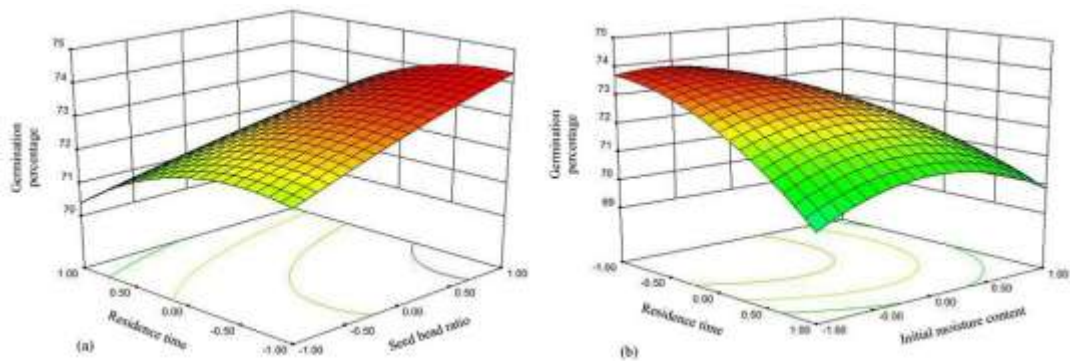


Fig. 4.4. Response surface plot for germination percentage of onion seed as a function of (a) residence time and seed bead ratio (b) residence time and initial moisture content while other variables are at centre point

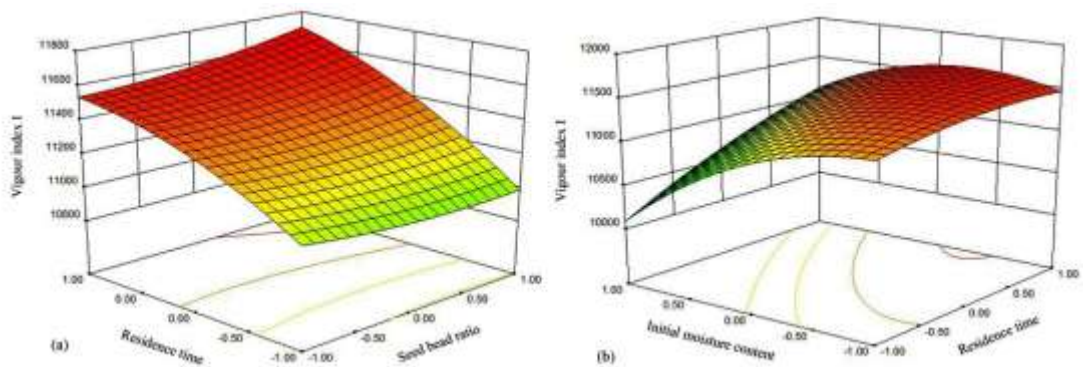


Fig. 4.5. Response surface plot for vigour index I of tomato seed as a function of (a) residence time and seed bead ratio (b) initial moisture content and residence time while other variables are at centre point

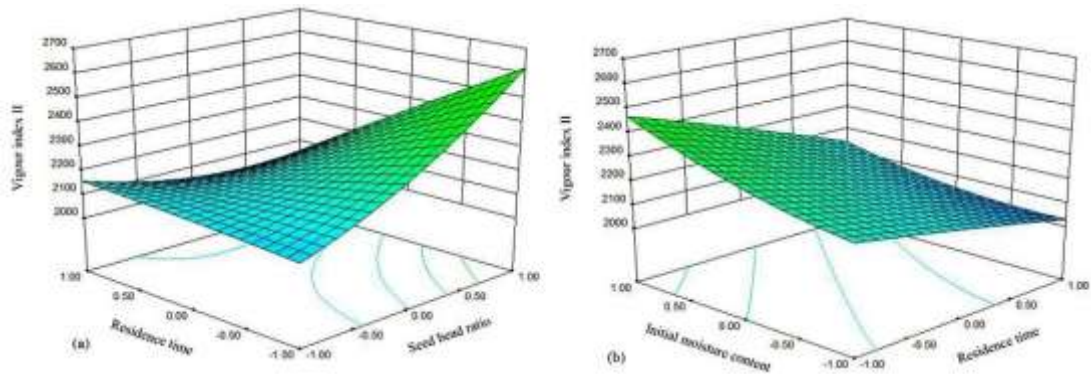


Fig. 4.6. Response surface plot for vigour index I of onion seed as a function of (a) residence time and seed bead ratio (b) initial moisture content and residence time while other variables are at centre point

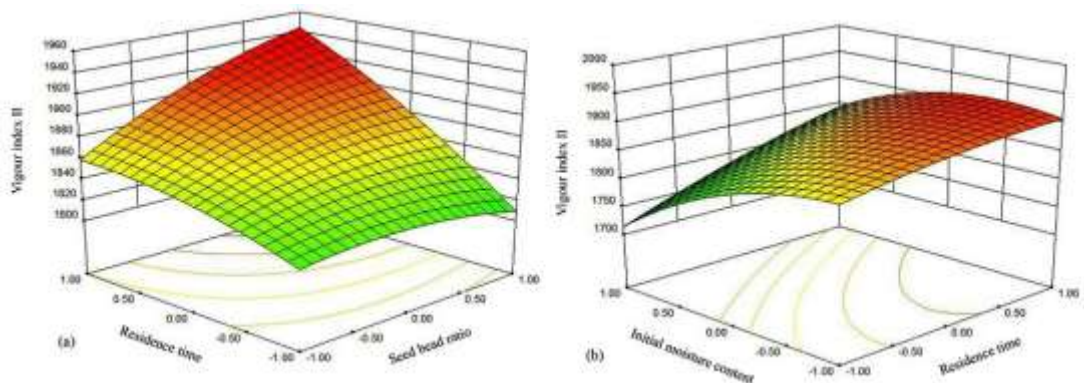


Fig. 4.7. Response surface plot for vigour index II of tomato seed as a function of (a) residence time and seed bead ratio (b) initial moisture content and residence time while other variables are at centre point

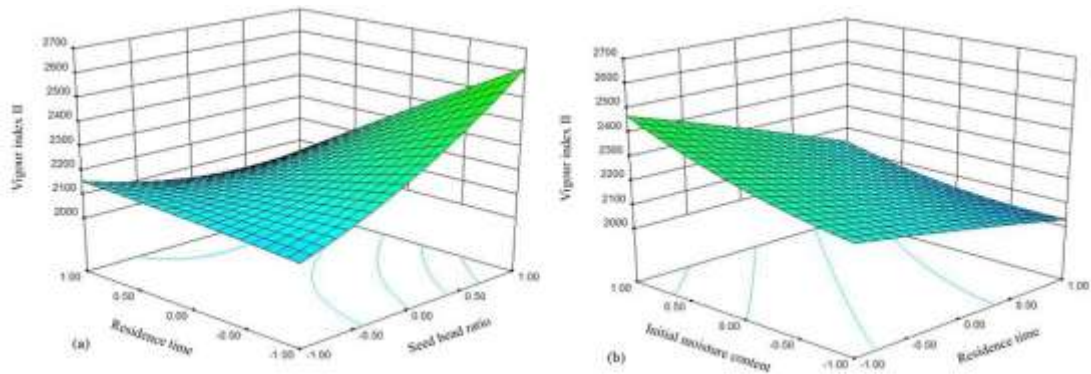


Fig. 4.8 Response surface plot for vigour index II of onion seed as a function of (a) residence time and seed bead ratio (b) initial moisture content and residence time while other variables are at centre point

4.7.2. Germination percentage

Effect of independent variables (X_1 , X_2 and X_3) on germination percentage for tomato and onion are presented fig. 4.3 and Fig. 4.4, respectively. Only two

process variables *i.e.* residence time and initial moisture content, were found significant effect on germination percentage ($p < 0.01$). On the other hand, the effect of seed bead ratio on germination percentage was observed to be insignificant. The positive effect of residence time on germination percentage may be due to the fact that longer residence time results in reducing moisture to lower levels which decreasing the amount of water available for physiological activities of seed. The dried tomato seed germination percentage was found in the range of 71 to 78%, which were significantly higher than IMCS (Indian Minimum Seed Certification Standards).

In case of onion seed, all the three process variables initial moisture content, seed bead ratio and residence time were found significant with respect to germination percentage. Seed bead ratio and initial moisture content was observed significant at 5% level whereas, residence time was significant even at 1% level. The positive correlation was found between seed bead ratio and germination percentage. It signified there was not any adverse effect on germination with the bead drying system. Residence time affected the germination negatively. It might be due to lower level of drying, which extracted the structural water of seed. The dried onion seed exhibited germination percentage in the range of 68 – 74 %.

Table 4.4. ANOVA and regression coefficients of the second order polynomial model of the various responses for tomato seeds

Predictor	Regression Coefficients			
	FMC	GP	VI I	VI II
Intercept	4.60	73.02	8036.58	2185.83
X_1	-0.27***	0.83**	-33.90	103.81
X_2	-0.80***	-1.12***	168.57	-127.97
X_3	0.18**	-0.79**	307.56**	91.63
X_1X_2	0.03	-0.25	81.58	-155.63
X_1X_3	-0.07	0.25	-139.18	13.13

X_2X_3	-0.20	0.75	-127.75	-35.87
X_1^2	0.01	-0.10	66.04	53.75
X_2^2	0.26***	-0.81**	116.70	-5.29
X_3^2	0.37***	-1.16***	235.43**	33.95
ANOVA				
R²	94.25	87.55	68.44	48.83
Model F value	18.23	7.80	2.40	1.06
CV	5.65	1.36	4.45	12.48
Lack of Fit	NS	NS	NS	

X_1 , coded seed-bead ratio; X_2 , residence time; X_3 , initial moisture content; NS, non significant; *** Significant at 1 % ($p < 0.01$); ** Significant at 5 % ($p < 0.05$).

4.7.3. Vigour index I

Figure 4.5 and 4.6 shows response surface plots of effect of independent variables on vigour index I of tomato and onion seeds, respectively. The dried tomato seeds exhibited vigour index-I in the range of 9626.1 to 11645.4. It was found varying from 7519 to 9335.7 for onion seed. Positive correlation was demonstrated by residence time for vigour index-I. Ultra drying of seed might be reducing physiological activity and thereby increasing of vigour index-I had been observed. However, initial moisture content illustrated negative correlation ($\beta = -391.16$) in tomato seed and positive correlation ($\beta = 307.77$) for onion seed. On the other hand there was not any significant effect of seed bead ratio on vigour index-I for both tomato and onion seed. The second order polynomial model fitted to experimental results was found significant ($p < 0.05$) only for tomato.

4.7.4. Vigour index II

The values of vigour index II ranged from 1934.4 to 1641.3 and 1768 to 3285 for tomato and onion seed, respectively. Fig. 4.7 and 4.8 depict the effect of independent variables on various responses. The regression analysis results (Table

4.3 and 4.4) showed that the seed bead ratio has no effect on vigour index-II. However, residence time was found to be negatively correlated with vigour index-II for onion, while it was positively ($p < 0.05$) in case of tomato. It was also strengthened by surface plots (Fig. 4.7 (a) and 4.8 (b)). The vigour index-II was found decreasing with increasing initial moisture content in case of tomato whereas, VI-II was found with higher IMC for onion seed. Quadratic second order polynomial model was found to be best fit for tomato seed only.

4.8. Optimization of Process Parameters

Numerical optimization of process variables was carried out with the help of Design Expert 8.0.1 software. Initially, optimization was carried out for individual response, followed by overall optimization was done for all the responses for tomato and onion seed. Optimization was carried out under certain applied conditions and to predict the corresponding responses as well. The applied constraints and the predicted values obtained for the various responses are reported in Table 4.5 to 4.8.

Table 4.5. Applied constrains to obtain optimized values of processing variables individually

<i>Variable</i>	<i>Condition</i>	<i>Lower limit</i>	<i>Upper limit</i>
Seed bead ratio	Minimize	1:0.33	1:1.17
Residence time	Minimize	1.3	14.7
Initial moisture content	Maximize	8.64	15.36

Table 4.6. Individual optimized responses[illegible]

<i>RT</i>	5.36	6.9	4.0	4.0	4.0	4.0	4.0	4.0
<i>IMC</i>	12.64	13.4	12.76	12.66	12.78	14.0	12.94	14.0

SBR, seed bead ratio; RT, residence time (h); IMC, initial moisture content (% d.b); FMC, final moisture content and GP, germination percentage.

Table 4.7. Applied constrains to obtain optimized values of processing variables and the predicted response for tomato

<i>Variable</i>	<i>Condition</i>	<i>Lower limit</i>	<i>Upper limit</i>	<i>Optimum value</i>
<i>Seed bead ratio</i>	Minimize	1:0.33	1:1.17	1:0.5
<i>Residence time</i>	Minimize	1.3	14.7	10.8
<i>Initial moisture content</i>	Maximize	8.64	15.36	11.84
<i>Responses</i>				
<i>Final moisture content</i>	Minimize	2.8	5.6	3.94
<i>Germination percentage</i>	Maximize	71	78	76.99
<i>Vigour index I</i>	Maximize	9626.1	11645.4	11334.5
<i>Vigour index II</i>	Maximize	1641.3	1934.4	1845.6

Table 4.8. Applied constrains to obtain optimized values of processing variables and the predicted response for onion

<i>Variable</i>	<i>Condition</i>	<i>Lower limit</i>	<i>Upper limit</i>	<i>Optimum value</i>
<i>Seed bead ratio</i>	Minimize	1:0.33	1:1.17	1:0.62
<i>Residence time</i>	Minimize	1.3	14.7	6.52
<i>Initial moisture content</i>	Maximize	8.64	15.36	13.62

<i>Responses</i>				
<i>Final moisture content</i>	Minimize	3.6	6.9	5.55
<i>Germination percentage</i>	Maximize	68	74	71.08
<i>Vigour index I</i>	Maximize	7519	9335.7	8541
<i>Vigour index II</i>	Maximize	1768	4285	2262.31

The optimum level of the selected variables was obtained by solving the regression equation using a multi-stage Monte-Carlo optimization (Conley, 1984) program and also by analysing the response-surface plots (Khuri and Cornell, 1987). Numerical optimization for the process parameters led to the preparation of a drying protocol for obtaining the best results. Desired goals were assigned for all the parameters for obtaining the numerical optimization values for the responses. All the processing parameters were minimized except initial moisture content. Final moisture was minimized while germination percentage, vigour index I and II were maximized. The coded values were first decoded into actual ratios as per the equations in Table 4.1 and then these ratios were transformed into actual variables by solving the algebraic equations. The overall optimum values obtained for seed bead ratio, residence time and initial moisture content in case of tomato seeds were 1:0.5, 10.8 hours and 11.84 percent, respectively. The corresponding values for responses *i.e.* final moisture content, germination percentage, vigour index I and II in case of tomato were 3.94 %, 76.99 %, 11334.5 and 1845.6, respectively. On the other hand, the optimum values for seed bead ratio, residence time and initial moisture content were 1:0.62, 6.52 and 13.62, respectively for onion seed,. The corresponding values for onion seed were found to be 5.55 %, 71.08 %, 8541 and 2262.31 for final moisture content, germination percentage, vigour index I and vigour index II, respectively.

4.9. Conclusion

The present study was analysed by CCRD for three independent parameters with five levels of each on process variables: seed bead ratio, residence time and initial moisture content. Prediction models were developed for each of the response. Model analysis with the help of various relevant statistical aids, such as F value,

coefficient of determination (R^2), CV and lack of fit, revealed that all the models, except for vigour I and II of onion, were found significant. The higher the initial moisture content reduced the germination percentage. It was found that the residence time significantly affected the seed vigour indices for tomato. However, the effect on seed vigour indices was not significant in onion seed.

Optimum values were obtained with the help of Design Expert 8.0.7.1 for all the process parameters by keeping seed bead ratio and residence time at minimum and initial moisture content at maximum, when the response final moisture content was minimized and germination percentage, vigour index I and II were maximized. The optimum process variables were different for the tomato and onion seed, which depict that they have structural, physical or genetical differences that affect these traits and determine seed quality. The optimum values obtained for seed bead ratio, residence time and initial moisture content were 1:0.5, 10.8 hours and 11.84 percent, respectively for tomato seed. The resulting values of response variables viz. final moisture content, germination percentage, vigour index I and vigour index II were found 3.94 %, 76.99 %, 11334.5 and 1845.6, respectively. Seed bead ratio, residence time and initial moisture content of 1:0.62, 6.52 and 13.62, respectively were found optimum for onion seed and the corresponding response values were 5.55 %, 71.08 %, 8541 and 2262.31 for final moisture content, germination percentage, vigour index I and vigour index II, respectively.

CHAPTER V

RESEARCH PAPER II

Performance Evaluation of Beads Drying for High Value Low Volume Seed

5.1. Abstract

Seed water influences the progress and kinetics of the most important biological reactions. The moisture content and storage temperature are main factors which determine the rate of the ageing process. The high moisture content in seed accelerates the respiration rate as well as activity of micro-organisms. With drying the adverse physiological activities may be reduced which leads to increased longevity and better seed quality. In the present study, beads were used as the drying medium and its performance was evaluated. Regeneration of beads was conducted with microwave oven and hot air oven. The microwave oven was found to be efficient as regeneration could be achieved within 20 minute; however hot air oven needed four hour for it. Drying with beads system did not exhibit any adverse effect on germination even in case of onion seed which is very susceptible to hot air drying. Furthermore, this drying method could be conducted at rural level as it does not require high investment as well as grid power. The regeneration of beads could be done in direct fire. The vigour test also depicted that there was not any negative effect of drying on vigour in case of either of seed under study.

5.2. Introduction

Seed being a living entity, its moisture content is critical factor which influences its longevity as water serves as a fluid medium and stabilizes the structures of macromolecules. The moisture content of seed is one of the important factors which determine the ageing process. The high moisture content in seed accelerates the respiration rate as well as activity of micro-organisms. Seed water influences the progress and kinetics of most important biological reactions. The moisture content is frequently higher (15-18%) at the time of harvest than the optimum to obtain the best potential life of seed. It is widely accepted that drying of seed prior to storage increases their longevity. Reducing seed moisture to low level

increases storability of some seed even under ambient conditions (Zheng,1998). Various methods have been adopted for drying of seed ranging from traditional; sun drying to sophisticated drying systems; fluidized bed systems. All these method uses air as drying media and its temperature as driving factor for drying. At higher temperature; drying increases however, threat to seed quality is also associated with higher temperature. Seed quality of high value low volume seed is very sensitive with drying temperature. Among high value low volume seed, tomato and onion seed are critical with hot air seed drying. Minor change of drying temperature can result in a reduced germination, vigor and/or shelf life considerably. Alternatively desiccant drying is one option. But normally desiccant drying is very slow process. Recently zeolite beads (desiccant) has been developed which can be used for seed drying (Asbrouck and Taridno, 2009). The beads have an extremely high capacity to adsorb water, even at very low air humidity, making them optimal drying material. A second nature of the drying beads is the generation of heat during the process of water adsorption. The adsorption process is fully reversible and of purely physical nature.

This study was aimed to evaluate performance of beads drying for tomato and onion seed and its practical viability for seed production sector.

5.3. Material and Methods

A nascent method of beads drying was investigated for onion and tomato seed. These seeds are critical for conventional drying system and poor storer. The details of the materials and equipment used for present study are described here.

5.3.1. Raw Material

Tomato seed cv. *Pusa Ruby* and Onion seed cv. *Nasik Dark Red* were procured from the local market as per requirement and stored in dry shaded place. These were used for the present study. Beads were procured from M/s Ambala Associates, Ambala, which were imported from RR Group, Taiwan.

The studies on Beads drying system for tomato and onion seeds were carried out in Division of Agricultural Engineering and Division of Seed Science and Technology, Indian Agricultural Research Institute; New Delhi during 2012-2013.

5.3.2. Microwave Oven

Domestic microwave (fig. 3.1) oven was used for regeneration of beads. A microwave oven is an appliance that heats a material by bombarding it with electromagnetic radiation in the microwave spectrum causing polarized molecules in the material, like water, to rotate and build up thermal energy in a process known as dielectric heating. Microwave ovens heat product quickly, uniformly and efficiently because excitation is fairly uniform in the outer 25–38 mm of; the product is more evenly heated throughout (except in thick, dense objects) than generally occurs in other heating techniques. The microwave oven used in the present study was of LG make capable of working on 220 V, 50-60 Hz, AC power source. The wattage was adjustable in the range of 140 to 800.

5.3.3. Hot Air Oven

Hot air oven Wisvo make (fig.3.2) was used for regeneration of beads. It was working on 220 V, 50 Hz, AC power supply. Its working temperature was in the range of 50 - 300 °C. In order get constant temperature inside the oven, a thermostat was equipped with heating element in series. Set and present temperature was displayed by LED display. It had double walled insulated rigid body. A circulation fan was installed in the oven to maintain uniform inside temperature. The provision of time control was also there. To keep the material inside there were removable aluminium trays arraigned vertically.

5.3.4. Portable Mini Data Logger

A portable mini data logger (fig. 3.4) was used for recording temperature and humidity of container where drying was experimented with beads. It had feature of setting the recording parameters i.e. time interval of measurable parameters. It was compact and battery operated. It contained data storage chip which can store 75000 data point. The logger had feature that the recorded data could be exported to external computer through EasyLog software in form of Microsoft Excel Sheet as well as chart form. Data logger was set using EasyLog software. It had a provision for setting the interval of recording data. It also had the facility for setting a point of time start of set parameters (temperature and relative humidity). These setting could be done by hooking the data logger to personal computer and using EasyLog

software. Recorded data was downloaded to personal computer by connecting the logger through USB port and its software.

5.4. Regeneration of Beads

Regeneration of beads implies the reactivation of beads so that they can be re-used for further drying. External heating causes the beads to lose adsorbed moisture. In the present study the beads were regenerated using Hot Air Oven and Microwave Oven.

5.4.1. Hot air oven regeneration

The weighed beads were kept in desiccators containing a layer water of depth 5 cm without touching the water. The desiccators with water and bead were subjected to constant temperature of 35 °C with closed lead condition for saturating the beads. At regular interval of 2 h beads were weighed up to reaching constant weight. This state of beads was considered as maximum water adsorption state. The conditioned beads were used for optimization of regeneration parameters. The conditioned beads of 250 g were exposed to temperature of 150, 200 and 250 °C and for 1, 2, 3 and 4 h in hot air oven in three replications. After elapsing the duration at specified temperature, beads were weighed on electronic balance of sensitivity of 0.001 g. The percentage loss of weight was calculated to evaluate regeneration process.

5.4.2. Microwave oven regeneration

The beads were fully hydrated using desiccators filled with plain water prior to regeneration in the same manner as mentioned in section 3.4.1. A Microwave Oven of LG make with 140 to 800 Wattage was used. The beads after attaining full saturation level were kept in domestic microwave at 800W, 640W and 480W for 10, 15 and 20 minutes. After elapsing the duration at specified temperature beads were weighed on electronic balance of sensitivity of 0.001 g. The percentage loss of weight was calculated to evaluate regeneration process. The energy consumption was recorded using an energy meter attached to the circuit.

Surface Area

Water adsorption by beads is a surface phenomenon. Hence, increase of available surface increases adsorption and consequently faster drying can take place. The physical dimensions of tomato seeds, onion seeds are given in appendix I. Surface area (S) of seeds was calculated using the following equation (Jain and Bal, 1997):

$$S = \frac{\pi BL^2}{(2L - B)}$$
$$B = \sqrt{WT}$$

Where,

L = length; mm

W= width; mm

T = thickness; mm

Average surface of seed was calculated for randomly selected 100 seed of tomato and onion, reparatory. The average surface area was multiplied by the number of seed in fixed volume (200 cm³) to know the surface area of seed in fixed volume. As during experimentation seed bead ratio was taken on volume basis. It all provided the available surface area of seed coming in contact with beads during beads drying process.

The beads were observed as spherical in shape Beads surface area was calculated using following equation:

$$S = \pi D^2$$

Where,

D = average diameter of bead; mm

The total surface area in fixed volume was calculated by multiplying number of beads in fixed volume with average calculated area of bead.

5.5. Results and Discussion

Beads are modified ceramic materials (aluminum silicates or “zeolites”) that specifically absorb and hold water molecules very tightly in their microscopic pores. It could be regenerated only by heating it by using any source of heat. The activated beads could be used for drying seed at room temperature. The evaluation of performance of beads drying for low volume high value seeds is discussed as follow.

5.5.1 Regeneration of beads

The water that was adsorbed during drying process was to be removed to use the beads subsequently. The removal of moisture from beads was considered as regeneration of beads. Regeneration of beads was carried out by two methods in the present study *i.e.* A. by using Hot air oven and B. by using domestic Microwave oven.

In hot air oven, beads were subjected to 150, 200 and 250 °C for 1, 2, 3 and 4 hours. The exposure of beads to elevated temperature increased the capacity of adsorbing moisture from surrounding. Regeneration temperature had shown significant effect on regeneration process (Fig. 5.1). It was observed that beads attained full regeneration at 250°C heating for 4 hours. However, at 200 °C regeneration yielded only 50 % regeneration of beads in 4 hours, as the beads contained 10% moisture content after exposure of beads for 4 hours at 200 °C. At the same time, regeneration at 150 °C depicted reduction of moisture in beads to 5 % only after 4 hours of heating. Steep decline of moisture was observed in case of regeneration at 250 °C than lower temperature regeneration. It all implied that the

beads heated at 250 °C for 4 hour could regenerate the beads effectively.

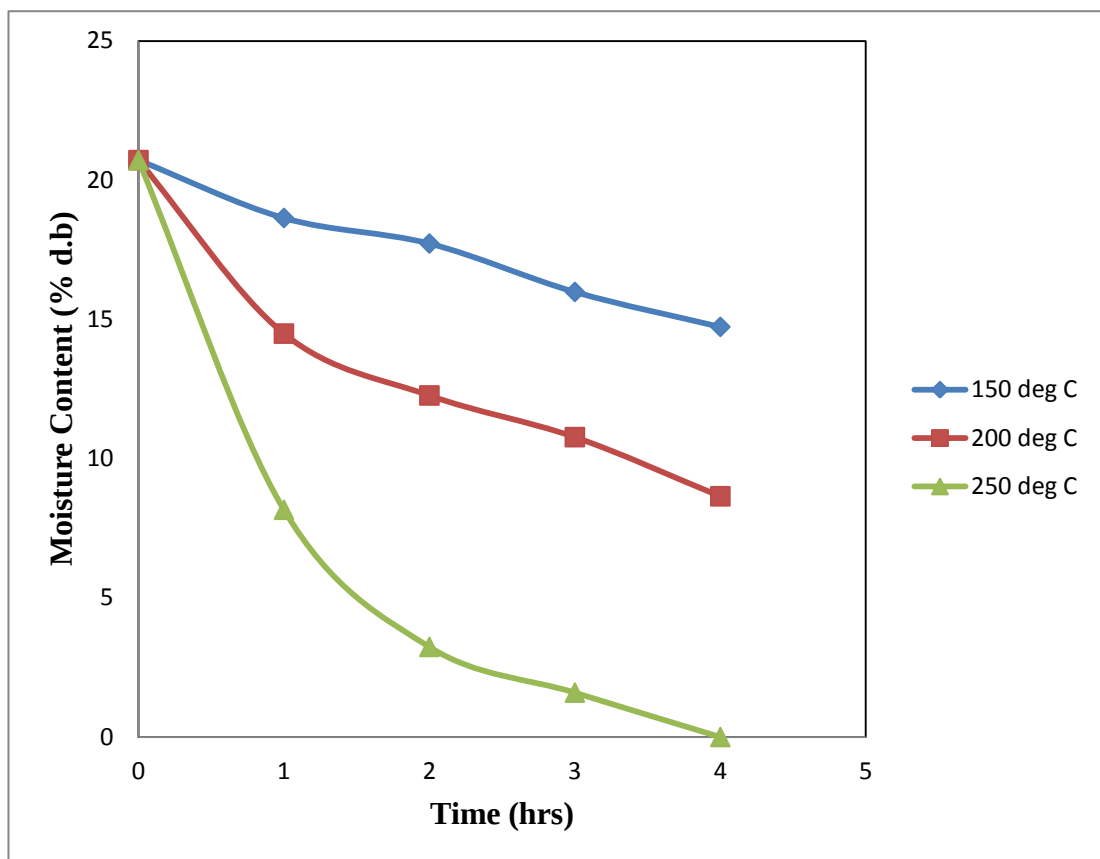


Fig. 5.1. Hot air oven regeneration graph

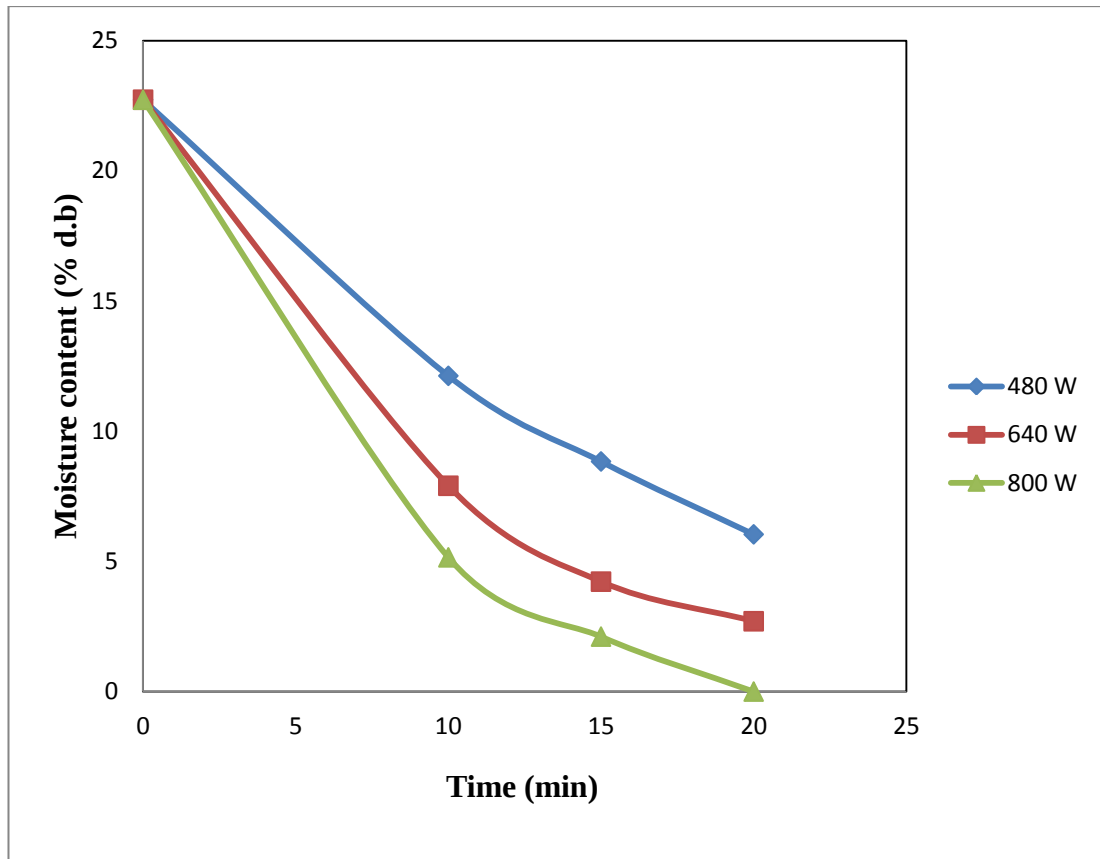


Fig. 5.2. Microwave oven regeneration graph

5.5.2. Regeneration by Microwave oven

Domestic microwave was employed for regeneration of beads. The decrease (Fig. 5.2) of moisture content of beads was found at all the three levels of wattage (480, 640 and 800). However, the reduction of moisture content was observed faster for 800 W than 640 and 480 W. The potential regeneration could be achieved within 20 minute at 800 W. However, at the lower wattage also resulted regeneration in the range of even at 640 and 480 W within 20 minute. It was evident from above; microwave regeneration process was faster than hot air oven method of regeneration. It might be due to uniform heating of beads to inner core level in process of microwave regeneration than hot air oven.

5.5.3. Surface Area of bead

The average surface area for one seed of tomato and onion was found to be 7.99 and 9.64 mm², respectively. The number of seeds present in specific volume of seed sample was calculated using fixed volume method and found to be 36364 and 22858 for tomato and onion, respectively. The average surface area of specific

volume of seed was therefore calculated as 290545 and 220351 mm² for tomato and onion seed sample, respectively.

The beads were observed as spherical in shape. Its average surface area was computed to 177.36 mm². The specific number of beads for fixed volume was reckoned. As volume basis seed beads ratio was used during experiment. For different levels of seed bead ratio bead surface area were computed and presented in Table 5.1.

Table 5.1. Surface area of beads at different experimental levels

Seed Bead Ratio	Bead Surface Area (mm²)
1:0.33	28909.68
1:0.5	43807.92
1:0.75	65623.2
1:1	87438.48
1:1.17	90985.68

5.5.4. Comparison of beads drying with hot air drying

It was found that the removal of moisture was slow in case of hot air drying in comparison of beads drying as only about 3 % within 4 h. It also had threat of heat stress. However, moisture reduction was in the range of 6 to 8 percent point (Table 5.2). The beads drying was found superior to hot air as there was not any structural stress to seed as the drying was taking place at surface only. After 4 hour of drying the moisture content of tomato seed reduced to 8.8% and 11.2% from 12 and 15%, respectively. While the moisture content of onion seed reduced to 10.1% and 12.1% from 13 and 15%, respectively.

Table 5.2. Moisture contents for tomato and onion seeds after hot air drying

Time (h)	Tomato seed		Onion seed	
	12%	15%	13%	15%
1	10.1	12.9	11.3	13.1
2	9.6	12.1	10.7	12.6
3	9.1	11.5	10.4	12.3
4	8.8	11.2	10.1	12.1

In case of beads drying, moisture content of tomato seed reduced to 5.3% for 4 hours from 14% moisture content at seed bead ratio of 1:0.5. Also, beads drying led to lowest moisture content of 2.8% in tomato seed with 12 hour duration for 1:1 seed bead ratio. The lowest moisture content obtained was 3.6% with beads at 1:0.75 ratio for 14.7 hours from 12% moisture content for onion seed. This shows the capacity of beads to yield ultra-drying of seed, which is proven aid for enhancing longevity of seed (Zheng *et al.*, 2001). The progress of beads drying was depicted through the recorded data by Data logger in in-situ condition (Appendix III)). It confirms the faster drying process during the beads drying.

5.5.5. Effect of Beads Drying on Seed Quality

There was not any adverse effect observed of beads drying system on seed quality traits (germination percentage, vigour indices). Initial seed quality parameter *i.e.* germination and vigour indices were 75%, 11220 (VI-I) and 1798 (VI-II) for tomato seed. The beads dried tomato seed also expressed germination percentage and VI-I and VI-II as more than 75%, 11645 and 9626, respectively. Interestingly, an increase of seed quality parameters was observed with beads drying system. It might be due to drying process of beads drying acted as invigoration.

Initial seed quality parameter *i.e.* germination and vigour indices were 72%, 7940.3 (VI-I) and 2194 (VI-II) for onion seed. The beads dried tomato seed also expressed germination percentage and VI-I and VI-II as more than 70%, 7519 and 9335.7, respectively. Interestingly, in this case also an increase of seed quality parameters was observed with beads drying system. It might be due to drying process of beads drying acted as invigoration.

CHAPTER VI

RESULTS AND DISCUSSION

Present investigation was carried out to study the viability of beads drying for tomato and onion seed. The experiments were conducted at five levels of seed-bead ratio, residence time and at initial moisture content of seed. The effect of the process variables on final moisture content, germination percentage and seed vigour indices were analysed.

The process parameters considered during the study were seed bead ratio (1:0.33, 1:0.5, 1:0.75, 1:1, 1:1.17), residence time (1.3, 4, 8, 12, 14.7 hrs) and initial moisture content (8.64, 10, 12, 14, 15.36).

The experiments were planned using Response Surface Methodology (Khuri and Cornell, 1987) with Central Composite Rotatable Design (CCRD) in three independent variables. A second order mathematical model was found best fit for all responses. The adequacy of the model was tested using coefficient of determination (R^2) and Fisher's F-test. The model was used to interpret the effects of variables namely seed-bead ratio, residence time and initial moisture content on responses viz. final moisture content, germination percentage, seed vigour index I and seed vigour index II. For every response, the best fit equations were developed in order to investigate the effect of independent variables on those responses and to select the range of variables for an acceptable product. Optimization of various process conditions was done using software Design-Expert 8.0.7.1.

Initially seed lots were conditioned to the experimental levels of moisture content and then mixed with specified ratio of beads for specified residence time. Final moisture content was measured after drying. Seed traits in the form of germination percentage, Vigour index-I and vigour index-II were evaluated as responses.

The final moisture content of tomato seed varied between 2.8 to 5.6 % and it ranged from 3.6 to 6.9 % for onion seeds. All the processing variables namely seeds bead ratio, residence time and initial moisture content had a significant effect upon final moisture content of tomato and onion seeds. The seed bead ratio had a significant ($p < 0.05$) negative effect on final moisture in case of tomato seeds while

this effect was significant at 1% in onion seeds. The decrease in final moisture content with increase in seed bead ratio may be attributed to the larger surface available for moisture adsorption. Residence time had significant ($p < 0.01$) negative effect, for both tomato and onion, on final moisture content. This decreasing effect may be because of the more time available for beads to adsorb moisture. Significant positive effect of initial moisture content of tomato ($p < 0.01$) and onion ($p < 0.05$) may be due to constant rate of adsorption by given quantity of beads in a given time.

For tomato seeds, the maximum and minimum values of germination percentage were 78 and 71 percent, respectively. Whereas, it ranged between 74 and 68 percent in case of onion seed. Only two process variables, residence time and initial moisture content, had a significant effect on germination percentage ($p < 0.01$) in case of tomato. Seed bead ratio did not affect the germination percentage of tomato seeds significantly. This result corroborates the fact that the use of beads is safe and doesn't affect the seed viability. The negative effect of initial moisture content was perhaps because of the adverse effect of moisture in seeds. However, positive effect of residence time on germination percentage may be due to the fact that longer residence time results in more moisture removal, thereby decreasing the amount of water available for physiological activities of seeds. However, all the three process variables had a significant effect on germination percentage for onion seed. Seed bead ratio and initial moisture content affected the germination percentage at 5% level whereas residence time was significant at 1% level. The positive correlation was found between seed bead ratio and germination percentage. Residence time affected the germination negatively. The negative effect of initial moisture content is perhaps because of the adverse effect of moisture in seeds.

The dried tomato seeds exhibited vigour index I in the range of 9626.1 to 11645.4. The values of vigour index I of onion seed varied from 7519 to 9335.7. The positive correlation was demonstrated by the significant effect of residence time. The reason for increase in vigour index I with increase in residence time may be because of the more moisture removal which eliminates the chance of any physiological spoilage. However the significant effect of initial moisture content showed a negative correlation ($\beta = -391.16$) in tomato seeds. Whereas this was positively correlated ($\beta = 307.77$) in case of onion. The effect of seed bead ratio was found to be non-significant for both tomato and onion seed with the examined levels of independent

variables. The second order polynomial model fitted to experimental results was found significant ($p < 0.05$) for tomato. But this model was non-significant in case of onion.

The values of vigour index II ranged from 1934.4 to 1641.3 for tomato and 1768 to 3285 for onion seed. Residence time was found be negatively correlated with vigour index II for onion, while this effect was positively significant ($p < 0.05$) in case of tomato. The vigour index II decreases with increasing initial moisture content in case of tomato whereas for onion seeds, vigour index II increasing with initial moisture. Quadratic second order polynomial model fitted to the experimental results was found to non-significant in case of onion.

Numerical optimization was carried out for the process parameters for the Design Expert 8.0.7.1 software was used for individual and simultaneous optimization of process variables. Desired goal were assigned for all the parameters for obtaining the numerical optimization values for the responses. Seed bead ratio and residence times were minimized and initial moisture content was maximized. Among response parameters, final moisture content was minimized while other three were maximized. The optimum values obtained for tomato seeds were 1:0.5, seed bead ratio, 10.8 hours of residence time and 11.84 %, initial moisture content. For onion seeds, the optimum values of process parameters were 1:0.62, seed bead ratio; 6.52 hours of residence time and 13.62 % initial moisture content.

Apart from model analysis and optimization of beads drying system, its performance was evaluated in the present study. Regeneration of beads which implies the removal of adsorbed moisture from the beads to ensure its reuse was carried out in two separate methods. In hot air oven, beads were subjected to 150, 200 and 250 °C for 1, 2, 3 and 4 hours. The exposure of beads to elevated temperature increased the capacity of adsorbing moisture from surrounding. Regeneration temperature had shown significant effect on regeneration process (Fig. 5.1.). It was observed that beads attained full regeneration at 250 °C heating for 4 hours. However, at 200 °C regeneration yielded only 50 % regeneration of beads in 4 hours, as the beads contained 10% moisture content after exposure of beads for 4 hours at 200 °C. At the same time, regeneration at 150 °C depicted reduction of moisture in beads to 5 % only after 4 hours of heating. Steep decline of moisture was observed in case of regeneration at 250 °C than lower temperature regeneration.

It all implied that the beads heated at 250 °C for 4 hour could regenerate the beads. Domestic microwave was employed for regeneration of beads. The decrease (Fig. 5.2) of moisture content of beads was found at all the three levels of wattage (480, 640 and 800). However, the reduction of moisture content was observed faster for 800 W than 640 and 480 W. The potential regeneration could be achieved within 20 minute at 800 W. However, at the lower wattage also resulted regeneration in the range of even at 640 and 480 W within 20 minute. It was evident from above; microwave regeneration process was faster than hot air oven method of regeneration. It might be due to uniform heating of beads to inner core level in process of microwave regeneration than hot air oven

The average surface area for one seed of tomato and onion was found to be 7.99 and 9.64 mm², respectively. The number of seeds present in specific volume of seed sample was calculated using fixed volume method and found to be 36364 and 22858 for tomato and onion, respectively. The average surface area of specific volume of seed was therefore calculated as 290545.96 and 220351.12 mm² for tomato and onion seed sample, respectively.

The beads were observed as spherical in shape. Its average surface area was computed to 177.36 mm². The specific number of beads for fixed volume was reckoned. As volume basis seed beads ratio was used during experiment. For different levels of seed bead ratio bead surface area were computed and presented in Table 5.1.

It was found that the removal of moisture was slow in case of hot air drying in comparison of beads drying as only about 3 % within 4 h. It also had threat of heat stress. However, moisture reduction was in the range of 6 to 8 percent point (Table 5.2). The beads drying was found superior to hot air as there was not any structural stress to seed as the drying was taking place at surface only. After 4 hour of drying the moisture content of tomato seed reduced to 8.8% and 11.2% from 12 and 15%, respectively. While the moisture content of onion seed reduced to 10.1% and 12.1% from 13 and 15%, respectively.

In case of beads drying, moisture content of tomato seed reduced to 5.3% for 4 hours from 14% moisture content at seed bead ratio of 1:0.5. Also, beads drying led to lowest moisture content of 2.8% in tomato seed with 12 hour duration for 1:1

seed bead ratio. The lowest moisture content obtained was 3.6% with beads at 1:0.75 ratio for 14.7 hours from 12% moisture content for onion seed. This shows the capacity of beads to yield ultra-drying of seed, which is proven aid for enhancing longevity of seed (Zheng *et al.*, 2001). The progress of beads drying was depicted through the recorded data by Data logger in in-situ condition (Appendix III). It confirms the faster drying process during the beads drying.

There was not any adverse effect observed of beads drying system on seed quality traits (germination percentage, vigour indices). Initial seed quality parameter *i.e.* germination and vigour indices were 75%, 11220 (VI-I) and 1798 (VI-II) for tomato seed. The beads dried tomato seed also expressed germination percentage and VI-I and VI-II as more than 75%, 11645 and 9626, respectively. Interestingly, an increase of seed quality parameters was observed with beads drying system. It might be due to drying process of beads drying acted as invigoration.

Initial seed quality parameter *i.e.* germination and vigour indices were 72%, 7940.3 (VI-I) and 2194 (VI-II) for onion seed. The beads dried tomato seed also expressed germination percentage and VI-I and VI-II as more than 70%, 7519 and 9335.7, respectively. Interestingly, in this case also an increase of seed quality parameters was observed with beads drying system. It might be due to drying process of beads drying acted as invigoration.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Vegetables play a major role for nutritional and economic security especially in Indian context, where major part of population is vegetarian. Vegetables have higher productivity, shorter maturity cycle, and high value and provide greater income leading to improved livelihoods. The major challenge, which lies ahead, is to develop technologies that enhance quality and productivity of vegetables under reducing land, declining natural resources and increasing biotic and abiotic stresses. More than 40 kinds of vegetables belonging to different groups, namely cucurbits, cole crops, solanaceous, root and leafy vegetables are grown in different agro-climatic situations of the country. Among vegetables, tomato and onion are the most essential ingredients for almost all Indian recipes. It is thus imperative for Indian economy, to have higher production and productivity of these two important crops. Though, a lot has been done with regard to increasing the yield of these crops but post harvest losses galore. Besides, these seeds are poor storers. The moisture content of seed is one of the important factors which determine the rate of the ageing process. The high moisture content seed accelerates the respiration rate as well as activity of micro-organisms. Seed water also influences the progress and kinetics of most important biological reactions. The moisture content is frequently higher (ranging 15-18%) at the time of harvest than the optimum to obtain the best potential life of seed. It is widely accepted that drying of seed prior to storage, increases their longevity. Reducing seed moisture to low level increases storability of some seeds even under ambient conditions. Though, many drying methods like hot air method, sun drying method have been employed to reduce the moisture content of seeds, but a need was felt to have a drying system in place that did not affect seed quality negatively and could be faster. This study was taken to optimize and investigate such a drying system wherein, zeolite beads are employed to adsorb the moisture from seeds thus leading to drying.

Experiments were conducted as per Central Composite Rotatable Design, and Response Surface Methodology was applied to the experimental data using statistical package DesignExpert 8.0.7.1. In the present study, five levels of three independent

parameters, seed bead ratio (1:0.33, 1:0.5, 1:0.75, 1:1, 1:1.17), residence times level (1.3, 4, 8, 12, 14.7 h) and initial moisture contents (8.64, 10, 12, 14, 15.36 %) were considered for studying the beads drying process. Effect of process parameters was optimized against the following responses: final moisture content, germination percentage, vigour index-I and vigour index-II. Prediction models were developed for each of the response. Model analysis was done with the help of various relevant statistical aids, such as F-value, coefficient of determination (R^2), CV and lack of fit. It revealed that all the models were statistically significant except the models for onion vigour indices. Optimum values were obtained by the numerical optimization with the help of Design Expert 8.0.7.1 Software for all the process parameters by assigning goals to them, when minimizing final moisture content and maximizing the other responses; germination percentage, vigour index-I and vigour index-II.

The optimum values obtained for seed bead ratio, residence time and initial moisture content were 1:0.5, 10.8 h and 11.84 percent respectively for tomato seeds. The resulting values of response variables viz. final moisture content, germination percentage, vigour index I and vigour index II were 3.94 %, 76.99 %, 11334.5 and 1845.6, respectively. Seed bead ratio, residence time and initial moisture content of 1:0.62, 6.52 and 13.62, respectively were found optimum for onion seeds. The corresponding response values were 5.55 %, 71.08 %, 8541 and 2262.31 for final moisture content, germination percentage, vigour index I and vigour index II respectively. These optimum values serve as a protocol for drying tomato and onion seeds.

It was found out that while drying with beads final moisture content reduced to 2.8 % for tomato and 3.6 % for onion. However, drying to the level with hot air system required more than triple time with the threat of quality deterioration. There was not any adverse effect observed of beads drying system on seed quality traits (germination percentage, vigour indices). The drying of onion and tomato seed from 12 – 15 % moisture content to 4 % moisture content could be done within four hours with beads at room temperature. The process was found high practical viability for rural conditions for enhancing longevity of poor storer seed.

Performance Evaluation of Beads Drying System

ABSTRACT

Tomato and onion are important vegetable crops of India. These two vegetables play a major role for nutritional and economic security especially in Indian context, where major part of population is vegetarian. The seed of these two vegetables are well known poor storer. At the same time ultra-low moisture content seed exhibits higher longevity (Zheng *et al.*, 1998). There are various drying methods; ranging from sun drying to highly complex mechanical drying system but they are known to have adverse effect on the seed quality parameters as drying at high temperature induces heat stress to seed. Zeolite beads which are inert adsorbent materials can be used for drying at room temperature. These zeolite beads can adsorb moisture at low relative humidity, thus are suitable for drying material to ultra-low moisture content. The seed of tomato cv. *Pusa Ruby* and onion cv. *Nasik Dark Red* with initial moisture content of 8.6 to 15.4 % (d.b) were dried at five levels of residence time (1.3, 4, 8, 12, 14.7 h) and five levels of seed bead ratio (1:0.33, 1:0.5, 1:0.75, 1:1, 1:1.17). Response Surface Methodology (RSM) was employed to optimize the parameter of drying in central composite rotatable design. Models were found to be significant for all the response variables namely, final moisture content (FMC), germination percentage (GP), vigour index-I (VI-I) and vigour index-II (VI-II) for tomato seed. In case of onion, models were observed to be significant for FMC and GP only. The optimum values of process variables was found to be 1:0.5, 10.8 h and 11.84 per cent, seed bead ratio, residence time and initial moisture content, respectively for tomato seed. Seed bead ratio, residence time and initial moisture content of 1:0.62, 6.52 h and 13.62 per cent respectively were found optimum for onion seed. Regeneration of beads was conducted with microwave oven and hot air oven. The microwave oven was found to be efficient as regeneration could be achieved within 20 minutes; however hot air oven needed four hour for it. Drying with beads system did not exhibit any adverse effect on germination even in case of onion seed which is very susceptible to hot air drying. Furthermore, this drying method could be conducted at rural level as it does not require high investment as well as grid power. The regeneration of beads could be done in direct fire.

Keywords: ultra-low drying, zeolite beads, RSM, regeneration

बीड्स से बीज सुखाने के प्रणाली की निष्पादन मूल्यांकन

सार

टमाटर और प्याज भारत की महत्वपूर्ण सब्जी फसलें हैं। इन दो सब्जियों की आबादी का बड़ा हिस्सा शाकाहारी है, जहां विशेष रूप से भारतीय संदर्भ में पोषण और आर्थिक सुरक्षा के लिए एक प्रमुख भूमिका निभाते हैं। इन दो सब्जियों के बीज में अच्छी तरह से गरीब स्टोरेज जाना जाता है। एक ही समय में अल्ट्रा कम नमी सामग्री बीज उच्च दीर्घायु (इंग एट अल., 1998) दर्शाती है। विभिन्न सुखाने तरीके हैं, सूर्य अत्यधिक जटिल यांत्रिक सुखाने प्रणाली को सुखाने से लेकर, लेकिन वे उच्च तापमान बीज को गर्मी तनाव लाती है पर सुखाने के रूप में बीज की गुणवत्ता के मानकों पर प्रतिकूल प्रभाव है जाना जाता है। निष्क्रिय लेनेवाला सामग्री रहे हैं जो जिओलाइट मोती कमरे के तापमान पर सुखाने के लिए इस्तेमाल किया जा सकता है। ये जिओलाइट मोती अल्ट्रा कम नमी सामग्री के लिए सामग्री सुखाने के लिए उपयुक्त हैं, इस प्रकार कम सापेक्ष आर्द्रता में नमी सोखना कर सकते हैं। टमाटर सीवी के बीज. पूसा रूबी और प्याज सीवी. 8.6-15.4% (डीबी) के प्रारंभिक नमी सामग्री के साथ नासिक डार्क रेड (1:0.33, 1:0.5 निवास समय के पाँच स्तरों (1.3, 4, 8, 12, 14.7 ज) और बीज मनका अनुपात के पाँच स्तरों में सूख गया , 1:0.75, 1:1, 1:1.17). प्रतिक्रिया भूतल पद्धति (RSM) केंद्रीय संयुक्त rotatable डिजाइन में सुखाने के पैरामीटर अनुकूलन करने के लिए नियुक्त किया गया था। मॉडल सब अर्थात् प्रतिक्रिया चर, अंतिम नमी की मात्रा (एफएमसी), अंकुरण प्रतिशत (जीपी), ताकत सूचकांक में (छठी में) और ताकत टमाटर बीज के लिए सूचकांक द्वितीय (छठी द्वितीय) के लिए महत्वपूर्ण होना पाया गया है। प्याज के मामले में, मॉडल ही एफएमसी और जीपी के लिए महत्वपूर्ण होने के लिए मनाया गया। प्रक्रिया चर के अधिकतम मूल्यों क्रमशः टमाटर बीज के लिए 1:0.5, 10.8 घंटे और प्रतिशत 11.84, बीज मनका अनुपात, निवास समय और प्रारंभिक नमी सामग्री, हो पाया था। बीज मनका अनुपात, निवास समय और क्रमशः

1:0.62, 6.52 घंटे और 13.62 फीसदी की प्रारंभिक नमी सामग्री, प्याज के बीज के लिए इष्टतम पाए गए. मोती के उत्थान माइक्रोवेव ओवन और गर्म हवा ओवन के साथ आयोजित किया गया. माइक्रोवेव ओवन उत्थान के 20 मिनट के भीतर प्राप्त किया जा सकता है के रूप में कुशल हो पाया था, लेकिन गर्म हवा ओवन इसके लिए चार घंटे की जरूरत है. मोती प्रणाली के साथ सुखाने भी गर्म हवा सुखाने के लिए बहुत संभावना है जो प्याज बीज के मामले में अंकुरण पर कोई प्रतिकूल प्रभाव प्रदर्शन नहीं किया था. यह उच्च निवेश के साथ ही ग्रिड बिजली की आवश्यकता नहीं है के रूप में इसके अलावा, इस सुखाने विधि ग्रामीण स्तर पर आयोजित किया जा सकता है. मोती के उत्थान प्रत्यक्ष आग में किया जा सकता है.

BIBLIOGRAPHY

- Abdul- Baki, A. and Anderson, J. D. 1973. Vigor determination in Soybean seed by multiple criteria. *Crop Sci.* **13**: 630-633.
- Aguilera, J. M., Lusas, E. W., Ubersax, M. A. and Zabik, M. E., 1982. Roasting of navy beans (*Phaseolus vulgaris*) by particle-to-particle heat transfer. *J. Food Sci.* **47**: 996-1000 and 1005
- Akpaetok, O. I. 1973. Shelled com drying with heated sand. M.S. Thesis, Univ. of Wisconsin
- Alikhani, Z. 1990. Zeolites as particulates medium for contact heating and drying of corn. Ph.D. Thesis. Macdonald college of McGill university, Quebec, Canada
- Amer, B. M. A., Morcos, M. A. and Sabbah, M. A. 2003. New Method for the Determination of Drying Rates of Fig Fruits Depending on Empirical Data under Conditions Suiting Solar Drying. The International Conference Institute of Agricultural Engineering, 18–19 September, 2003, LUA Raudondvaris, Lithuania
- Arboleda, J. R., Manalo, A. S. and Khan, A. U. 1973. Accelerated drying of paddy. *Annales de technologic* **22**(3): 257-273
- Asbrouck, J. V. and Taridno, P. 2009. Fast field drying as a method to maintain quality, increase shelf life and prevent post harvest infections in *Cumis sativum* L. *Journal of Food and Agro-Industry*. Special Issue, S133-S137
- Babitt, J. D. 1949. Observations on the permeability of hygroscopic materials to water vapours. *Canadian Journal of Research*, **18**(4): 624-628
- Barakade, A. J., Lokhande, T. N. and Todleari, G. O. 2011. Economics of onion cultivation and its marketing pattern in Satara district of Maharashtra. *International Journal of Agricultural Sciences*, **3**(3):110-117
- Barrozo, M. A. S., Felipe, C. A. S., Sartori, D. J. M. and Freire, J. T. 2006. Quality of Soybean Seeds Undergoing Moving Bed Drying: Countercurrent and Crosscurrent Flows. *Drying Technology*, **24**: 415-

- Bernal, I. Lugo and Leopold, A. C. 1998. The dynamics of seed mortality. *Journal of Experimental Botany*, **49**(326): 1455-1461
- Chai, J., Ma. R., Li. L. and Du, Y. 1998. Optimum moisture content of seeds stored at ambient temperature. *Seed Science Research*, **8**, Supplement-NO. 1, 23-28
- Chancellor, WJ. 1968. A simple grain drier using conducted heat. *Trans ASAE* **11**: 857-862.
- Chen, Z. H., Gu, J. C., Li, X. F., Yun X. J. and Gao, H. 2011. Effect of ultradrying treatment on seed storage of *Hedysarum leave*. *Acta Practaculturae Sincia*, **20**(1): 148-154
- Cheng, Z., Guangwen, Z., Jiashu, H., Minfang, Z. and Xingmin, J. 2001. Aging resistance of ultradry onion seeds and its free radical scavenging. *Journal of Zhejiang University*, **27**(2): 139-144
- Chowdhary, R. K. 2004. Impact of quality seed and seed technology research in transformation of agriculture in India. *Proceedings of National Conference on Seed: A Global Prospective*. pp 34 NASC, New Delhi.
- Conley, W. C. 1984. Computer Optimization Techniques. Princeton, NJ: Petrocelli Books, pp. 147–163
- Crapiste, G. H. and Rotstein, E. 1997. Design and Performance Evaluation of Dryers. "Handbook of *food engineering practice*". CRC Press, Boca Raton, PP. 125-166.
- Danziger, M. T., Steinberg, M. P., and Nelson, A. I. 1972. Drying field corn with silica gel. *Transactions of the ASAE*, **15**: 1071-1074
- Dhaliwal, S. S., Singh, P. P. and Sukhmeet, S. 2009. Design and development of compact dessicant seed dryer. *Agricultural Mechanization in Asia, Africa and latin America*, **40**(4): 75-80
- Doijode, S. D. 1993. Germinibility and longevity of onion seeds under different drying methods. *Progressive Horticulture*. **22** (1-4): 117-120

- Finney, E.E., Mohsenin, N.N., and Hovanesian, J.D. 1963. The thermal efficiency of conduction drying of shelled maize and the effect of temperature and kernel injury on the drying rate. *IAER* **8**: 62-69
- Flanigan, E. M., 1984. Adsorption properties of molecular sieve Zeolites. In: *Zeolites in Agriculture* (W.G. Pond and F.A. Mumpton, eds.) Eastview Press, Boulder, Colorado, pp 55-68
- Graham, V. A., Bilanski, W. K. and Menzies, D. R. 1983. Adsorption grain drying using bentonite. *Transactions of the ASAE*, **26**: 1512-1515
- Hall, G.E. and Hall, C.W. 1961. Drying shelled corn by conduction heating. *Agric. Eng.* **42**: 186-187, and 196.
- Hong, T. D., Ellis, R. H., Astley, D., Pinnegar, A. E., Groot, S. P. C. and Kraak, H. L. 2005. Survival and Vigour of ultradry seeds after ten years of hermetic storage. *Seed Science and Technology*, **33**(2): 449-460
- Harrington, J. F. 1960. Drying, storing and packaging seed to maintain germination. *Seed Man's Digest*, **1**: 16-18
- Harrington, J.F. 1972. Seed storage and longevity. *Seed Biology*, **3**: 145-245
- Hay, F.R., Thavong, P., Taridno, P. and Timple, S. 2012. Evaluation of zeolite 'seed drying beads' for drying rice seeds to low moisture content prior to long storage. *Seed science and Technology*, **40**: 374-395
- Henderson, S. M. and Perry, R. L. 1976. *Agricultural Process Engineering*. The AVI Publishing Company, Inc., West Port, Connecticut, p p. 303
- Hu, W. M., Duan, X. M. and Ruan, S. L. 2002. Effects of ultradry treatment and long term storage on viability and vigor of corn and watermelon. *Journal of Zhejiang University (Agriculture & Life Sciences)* **28**(1): 34-41
- Jain, R.K. and Bal, S. 1997. Properties of pearl millet. *Journal of Agricultural Engineering Research*, **66**: 85-91
- Javaregowda, S., Talukdar, K. C. and Ramaiah, H. 1989. Studies on drying characteristics of tomato seeds (Pusa Ruby) (*Lycopersicon esculentum* Mill.). *Progressive Horticulture*, **21**(3-4): 296-299

- Javaregowda, S., Talukdar, K. C. and Ramaiah, H. 1990. Effect of drying methods on seed quality in tomato (*Lycopersicon lycopersicum*). *Seed Research*, **18**(2): 126-129
- Jiang, Y. B., Zheng, Q. H., Wang, C. Z. and Guo, Y. X. 2009. Effects of ultradrying storage on vigour and anti oxidants activity of *Cichoriun intybus* seeds. *Acta Practaculturae Sincia*, **18**(5): 93-97
- Keey, R. B. 1972. Drying principles and practice. Pergamon Press, Oxford, 358 p
- Kelly, C. F. 1939. Methods for drying grain on the farm. *Agric. Eng.* **20**(4): 135-138
- Khan, A. U., Amilhussin, A., Arboleda, I. R., Manola, A. S. and Chancellor, W. J. 1973. Accelerated drying of rice using heat conducting media. ASAE paper No 73-321
- Khuri, A. I. and Cornell, J. A. 1987. Response Surfaces, Design and Analyses. Marcel Dekker, New York, YN.
- Kozlowski, T. T. 1972. *Seed Biology*, Vol. 3, Academic Press, New York, pp.351-356
- Kreyger, J. 1954. Drying and storage of seed. *Zaadbelangen*, **8**: 1-23
- Kroll, K., Mujumdar, A.S. and Menon, A.S. 1980. Drying since the millenniums. In *Drying '80* (A.S. Mujumdar, ed.), Hemisphere Pub. Corp., Washington, 2:485-494.
- Lapp, H. M. and Manchur, L. R. 1974. Drying oilseeds with a solid heat transfer medium. *CSAE Paper No.* 74-504
- Lapp, H. M., Mittal, G. S. and Townsend, I.S. 1977. Drying wheat with heated sand. *CSAE paper no.* 77-105.
- Lin, J. and Zheng, G. H. 1993. Study of ultradrying sorghum seeds. *Plant Physiology Communications*, **29**(6):435-436
- Madamba, P. S. and Lopez, R. I. 2002. Optimization of the Osmotic Dehydration of Mango (*Mangifera indica* L.) Slices. *Drying Technology*, **20**: 1227-1242
- Madamba, P. S. and Liboon, F. A. 2001. Optimization of the Vacuum

- Dehydration of Celery (*Apium graveolens*) Using the Response Surface Methodology. *Drying Technology*, **19**: 611–626
- Madamba, P. S. 2002. The Response Surface. Methodology: An Application to Optimize Dehydration Operations of Selected Agricultural Crops. *Food Science and Technology*, **35**: 584–592
- Magalhes, P. M. and Groth, D. 1992. Effect of various drying processes on the physiological quality of seeds of *Brachiaria humidicola* (Rendle). *Schweick. Revista Brasileira de Sementis*, **14**(2): 195-200
- Marcos-Filho, J., Chamma, H. M. C., Casagrande, J. R. R. and Marcos, E. A. 1994. Effect of Harvesting Time on Seed Physiological Quality, Chemical Composition and Storability of Soybeans. *Scientia Agrícola*, **51**: 298-304
- McDonald, M. B. and Copeland O. L., 1999. Principles of seed science and technology. Kluwer Academic Publishers Group, Dordrecht.
- Mittal, G. S., Lapp, H. M. and Townsend, J. S. 1985. Feasibility of drying wheat with various solid heat transfer media. *Can. Agric. Eng.* **27**(2): 121-125.
- Mohsenin, N. N. 1986. Physical Properties of Plant and Animal Materials (2nd edn.). Gordon and Breach Science Publications, New York
- Montgomery, D. C. 2001. Design and Analysis of Experiments, 5th Ed., Wiley, New York. pp 455-492
- Mullen, K. and Ennis, D. M. 1979. Rotatable Designs in Product Development. *Food Technology*, **33**: 74–80
- Mumpton, F. A. 1978. A new industrial mineral commodity. Natural Zeolites, Pergamon Press, Oxford, pp 3-27
- Mumpton, F. A. 1984. Natural Zeolite. Zeo-Agriculture, pp 33-34
- Myers, R. H. 1971. Response Surface Methodology. Boston: Allyn and Bacon, Inc.
- Myers, R. H. and Montgomery, D. C. 2002 Process and Product Optimization Using Designed Experiments. "Response Surface Methodology". 2nd Edition, John Wiley and Sons, Inc., New York, PP. 328–335
- Oxley, T.A. 1948. The scientific principles of grain storage. Northern Pub. Co.

Ltd., Liverpool, 103 p

- Philpot, R.. 1976. Principles and practices of drying. Miss State University Short Course. *Seeds Mess Proceedings*, **16**: 23-40
- Prasad, N. R. and Tripathi, B. K. 1999. Influence of method and duration of drying on the moisture content and germination of sugarcane true seed. *Indian Sugar*, **49**(3): 199-202
- Pruti, J. S. 1993. Major spices of india. Crop management and post harvest technology. *Indian Council of Agricultural Research*, New Delhi
- Raghavan, G. S. V. 1973. Heat transfer studies using granular media. PhD Thesis, University of Colorado
- Sherwood, T. K. 1931. Application of theoretical diffusion equations to the drying of solids. *Transactions of the American Institute of Chemical Engineers*, **27**: 190-202
- Sibley, K. J. and Raghavan, G. S. V. 1985. Parameters affecting grain drying by immersion in a hot particulate medium. *Drying Tech.* **3**(1): 75-99
- Singh, G., Singh, H. and Dillon, T. S. 1985. Some aspects of seed extraction in tomato. *Seed Research*, **13**(2): 67-72
- Sogi, D.S., Shivhare, U.S., Garg, S.K., Bawa, A.S. 2001. Water sorption isotherm and drying characteristics of tomato seeds. *Biosystems Engineering* **84**: 297-301.
- Sturton, S. L. Bilanski, W. K. and Menzies, D. R. 1983. Moisture exchange between corn and the desiccant bentonite in an intimate mixture. *Canadian Agricultural Engineering*, **23**(1): 139-141
- Xiorong, H., Yunlan, Z., Chenglen, H. and Mei, T. Chen Shuping. 1998. A comparison of methods of drying seeds: Vacuum freeze drier versus silica gel. *Seed science research*, Supplement 1, 29-33
- Zeng, L., Zhao, L. J., Sun, Q. and Xu, X. W. 2006. Effects of ultradrying treatment on and storage temperature on vigour and physiological changes in *salvia splendens* seeds. *Scientia Agricultura Sinica*, **39**(10): 2076-2082

- Zhang, M., Li, C., Ding, X. and Cao, C. W. 2003. Optimization for Preservation of Selenium in Sweet Pepper under Low- vacuum Dehydration. *Drying Technology*, 21: 569–580
- Zhang, X. Y. and Tao K. L. 1988. Silica gel seed drying for germplasm conservation. *Plant Genetic Resource Newsletter*, **75-76**: 1-5
- Zheng, X. Y., Li, X. Q. and Chen, H. 2001. Effect of different ultra drying methods on vegetable seeds for long term storage. *Acta Horticulture Sinica*, **28**(2): 123-127
- Zode, N. G. 1997. Studies on seed viability in groundnut (*Arachis hypogaea* L.). *Annals Of Plant Physiology*, **11**(2): 117-122

APPENDIX I
Physical Dimensions of Tomato Seeds

Length (mm)	Width (mm)	Thickness (mm)	B value	S. Area (mm²)
3.75	2.37	0.69	1.28	9.08
3.1	2.07	0.79	1.28	7.84
3.51	2.23	0.88	1.40	9.64
3.36	2.1	0.68	1.19	7.67
3.65	2.52	0.61	1.24	8.56
3.49	2.32	0.7	1.27	8.54
3.9	2.46	0.8	1.40	10.47
3.64	2.89	0.91	1.62	11.92
3.43	2.55	0.79	1.42	9.64
3.07	2.23	0.9	1.42	8.88
3.59	2.25	0.73	1.28	8.79
3.38	2.55	0.79	1.42	9.53
3.56	2.07	0.73	1.23	8.30
3.17	2.19	0.64	1.18	7.24
3.7	2.15	0.63	1.16	8.02
3.36	2.34	0.67	1.25	8.12
3.01	2.01	0.64	1.13	6.60
3.02	2.2	0.55	1.10	6.38
3.26	2.02	0.77	1.25	7.89
3.32	2.72	0.72	1.40	9.24
3.43	2.23	0.58	1.14	7.34
2.92	2	0.77	1.24	7.22
3.41	2.09	0.68	1.19	7.73
3.32	2.15	0.6	1.14	7.14
3.2	2.18	0.79	1.31	8.29
3.85	2.58	0.69	1.33	9.76
3.54	2.37	0.57	1.16	7.73
3.18	2.3	0.68	1.25	7.77
3.35	2.07	0.73	1.23	7.92
3.92	2.26	0.68	1.24	9.06
3.3	2.03	0.91	1.36	8.87
3.63	2.23	0.88	1.40	9.89
3.4	2.4	0.56	1.16	7.46
3.42	2.33	0.6	1.18	7.68
3.77	2.01	0.72	1.20	8.47
3.46	2.06	0.72	1.22	8.03
3.68	2.17	0.64	1.18	8.11
3.95	2.44	0.72	1.33	9.88
3.5	2.16	0.73	1.26	8.41
3.45	2.15	0.83	1.34	8.97
3.35	2.51	0.7	1.33	8.69

3.86	2.25	0.74	1.29	9.39
3.27	2.17	0.79	1.31	8.40
3.61	1.83	0.74	1.16	7.86
3.3	2.4	0.76	1.35	8.80
2.96	1.84	0.78	1.20	6.98
3.34	1.87	0.59	1.05	6.54
3.21	1.93	0.68	1.15	7.03
2.53	2.28	0.74	1.30	6.94
4	2.13	0.72	1.24	9.20
3.93	2.19	0.8	1.32	9.82
3.47	2.26	0.69	1.25	8.30
2.78	1.7	0.56	0.98	5.16
3.32	2	0.67	1.16	7.31
2.91	1.87	0.54	1.00	5.55
2.98	2.03	0.67	1.17	6.78
3.39	2.4	0.81	1.39	9.34
3.32	2.06	0.56	1.07	6.68
3.83	2.45	0.77	1.37	10.06
3.88	2.18	0.69	1.23	8.87
3.31	2.03	0.89	1.34	8.76
3.46	2.07	1	1.44	9.87
3.05	2.06	0.8	1.28	7.79
3.35	2.25	0.75	1.30	8.48
3.28	2.46	0.78	1.39	9.04
3.24	2.36	0.71	1.29	8.23
3.63	1.82	0.72	1.14	7.75
3.32	1.88	0.63	1.09	6.78
3.45	1.95	0.59	1.07	6.88
3.15	1.7	0.52	0.94	5.47
3.73	2.52	0.77	1.39	10.03
3.52	2.25	0.83	1.37	9.37
2.9	2.06	0.65	1.16	6.58
2.94	2.05	0.6	1.11	6.31
3.27	2.69	0.68	1.35	8.75
3.48	1.79	0.68	1.10	7.16
3.19	2.06	0.7	1.20	7.41
3.23	2.17	0.62	1.16	7.17
3.38	2.1	0.62	1.14	7.28
3.13	2.29	0.7	1.27	7.80
2.71	2.11	0.46	0.99	5.12
3.37	2.14	0.55	1.08	6.84
2.72	1.54	0.59	0.95	4.94
2.84	1.93	0.61	1.09	5.98
2.72	2	0.69	1.17	6.40
3.59	2	0.73	1.21	8.19

2.89	2.1	0.76	1.26	7.34
3.36	1.84	0.77	1.19	7.63
3.8	1.83	0.6	1.05	7.25
3.27	1.7	0.77	1.14	7.12
3.34	1.78	0.66	1.08	6.78
3.77	2.31	0.77	1.33	9.59
3.02	1.64	0.85	1.18	6.96
3	2.33	0.72	1.30	7.78
3.58	2.4	0.73	1.32	9.13
3.11	1.98	0.59	1.08	6.39
3.55	2.01	0.63	1.13	7.45
3.16	2.01	0.6	1.10	6.59
3.77	1.93	0.77	1.22	8.61
3.47	2.37	0.86	1.43	9.79

APPENDIX II
Physical Dimensions of Onion Seeds

Width (mm)	Length (mm)	Thickness (mm)	B value	S. Area (mm²)
1.31	3.15	1.43	1.37	8.65
1.58	3.19	1.42	1.50	9.80
1.64	2.92	1.54	1.59	10.01
1.44	3.27	1.32	1.38	8.97
1.67	3.2	1.98	1.82	12.76
1.78	3.39	1.67	1.72	12.31
1.75	2.99	1.36	1.54	9.76
1.4	3.37	1.93	1.64	11.50
1.7	2.67	1.54	1.62	9.73
2.08	3.3	1.23	1.60	10.94
1.86	3.17	1.34	1.58	10.46
1.66	2.86	1.81	1.73	11.17
2	3.26	1	1.41	9.24
1.66	2.95	0.34	0.75	3.99
1.27	3.3	1.23	1.25	7.99
1.6	3.24	1.67	1.63	11.12
1.52	3.24	1.36	1.44	9.40
2.22	3.57	1.24	1.66	12.11
2.04	3.29	1.63	1.82	13.03
1.4	3.05	1.54	1.47	9.26
1.8	3.16	1.98	1.89	13.36
1.63	3.07	1.21	1.40	8.78
1.34	3.02	1.4	1.37	8.40
1.35	3.06	1.71	1.52	9.71
1.45	3.52	1.28	1.36	9.34
1.76	3.29	1.27	1.50	9.99
1.45	2.78	1.97	1.69	10.60
1.31	3.24	1.25	1.28	8.11
1.22	3.27	1.34	1.28	8.16
1.61	3.07	1.56	1.58	10.30
1.33	2.9	1.26	1.29	7.59
1.44	3.11	1.63	1.53	9.93
1.79	3.29	1.43	1.60	10.92
1.47	3.14	1.32	1.39	8.82
2	2.86	1	1.41	8.44
1.56	3	1.34	1.45	8.97
1.47	2.9	1.32	1.39	8.35
1.48	2.83	1.76	1.61	10.03
1.45	2.96	1.65	1.55	9.73
1.54	3.09	1.38	1.46	9.26
1.91	3.07	1	1.38	8.60

1.58	2.73	1.56	1.57	9.44
1.3	2.76	1.83	1.54	9.28
1.6	2.77	1.53	1.56	9.48
1.81	2.54	1.57	1.69	10.06
1.38	2.77	1.92	1.63	10.02
1.5	3.17	1.43	1.46	9.48
1.52	2.98	1.32	1.42	8.69
1.81	3.39	1.1	1.41	9.48
1.56	3.41	1.2	1.37	9.16
1.59	3.4	1.5	1.54	10.67
1.27	3.38	1.21	1.24	8.06
1.35	3	1.34	1.34	8.17
1.5	3.15	1.21	1.35	8.48
1.31	3.3	1.45	1.38	9.03
1.78	3.1	1.58	1.68	11.19
1.89	3.2	1.27	1.55	10.27
1.58	3.31	1.29	1.43	9.46
1.75	2.87	1.36	1.54	9.51
1.58	3.14	1.29	1.43	9.11
1.5	3.15	1.43	1.46	9.44
1.58	3.25	1.69	1.63	11.14
1.53	3.14	1.52	1.52	9.93
1.6	3.08	1.57	1.58	10.32
1.55	2.78	1.42	1.48	8.83
1.53	2.98	1.41	1.47	9.12
1.49	3.16	1.45	1.47	9.50
1.4	2.96	1.43	1.41	8.64
1.6	2.66	1.58	1.59	9.47
1.49	3.14	1.1	1.28	7.93
1.46	2.73	1.6	1.53	9.10
1.34	3.53	1.43	1.38	9.54
1.53	3.18	1.48	1.50	9.84
1.44	2.89	1.48	1.46	8.86
1.53	3.24	1.09	1.29	8.20
1.92	3.19	1.87	1.89	13.50
1.37	3.35	1.3	1.33	8.76
1.42	2.51	1.41	1.41	7.76
1.31	2.74	1.8	1.54	9.18
1.61	3.14	1.36	1.48	9.54
1.9	2.84	1.25	1.54	9.43
1.74	2.95	1.38	1.55	9.73
1.57	3.19	1.11	1.32	8.34
1.52	2.96	1.32	1.42	8.65
1.56	3.05	1.67	1.61	10.51
1.61	3.02	1.43	1.52	9.61

1.66	3	1.74	1.70	11.17
1.8	3.56	1.61	1.70	12.50
1.66	2.9	1.31	1.47	9.00
1.48	2.83	1.96	1.70	10.82
1.47	2.97	1.4	1.43	8.82
1.45	3.01	1.26	1.35	8.24
1.77	2.92	1.35	1.55	9.64
1.62	3.16	1.98	1.79	12.40
1.64	3.21	1.34	1.48	9.71
1.45	3.43	1.46	1.45	9.94
1.66	2.95	1.34	1.49	9.24
1.8	3.05	1.58	1.69	11.16
1.62	3.23	1.11	1.34	8.58
1.51	3.04	1.34	1.42	8.86

APPENDIX III

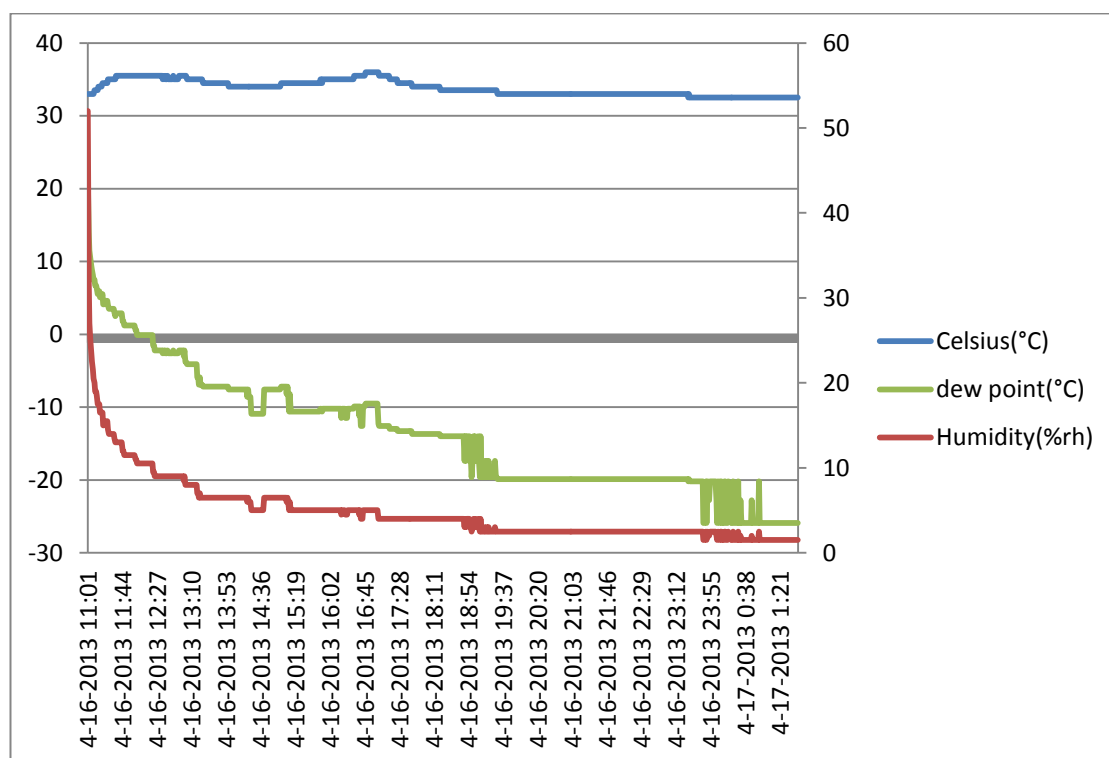


Fig a. Relative humidity variation in airtight containers with tomato seeds at seed bead ratio of 1:0.75 for 14.7 hours

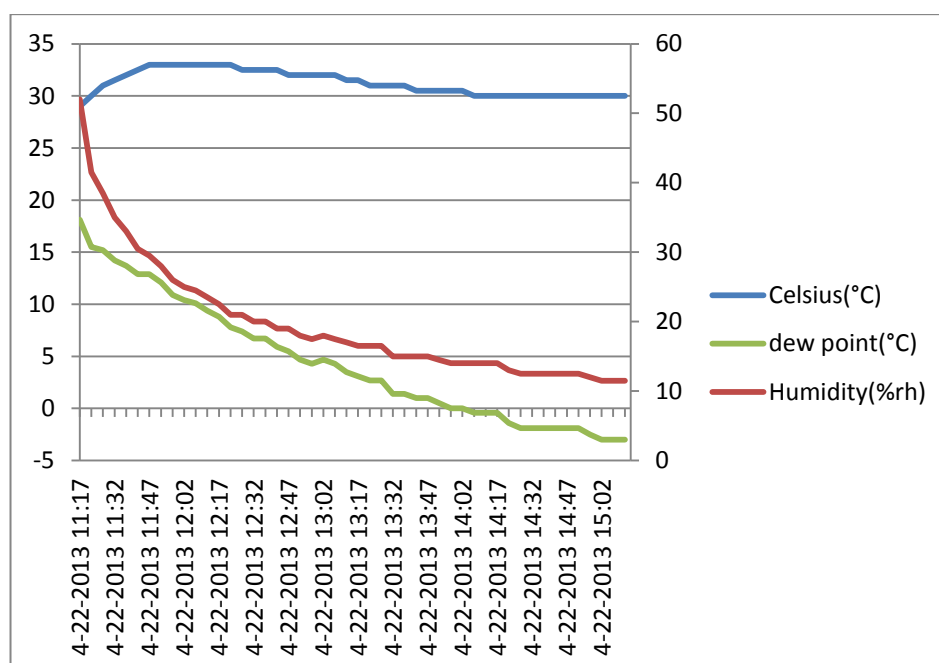


Fig. b. Relative humidity variation in airtight containers with tomato seeds at seed bead ratio of 1:0.5 for 4 hours

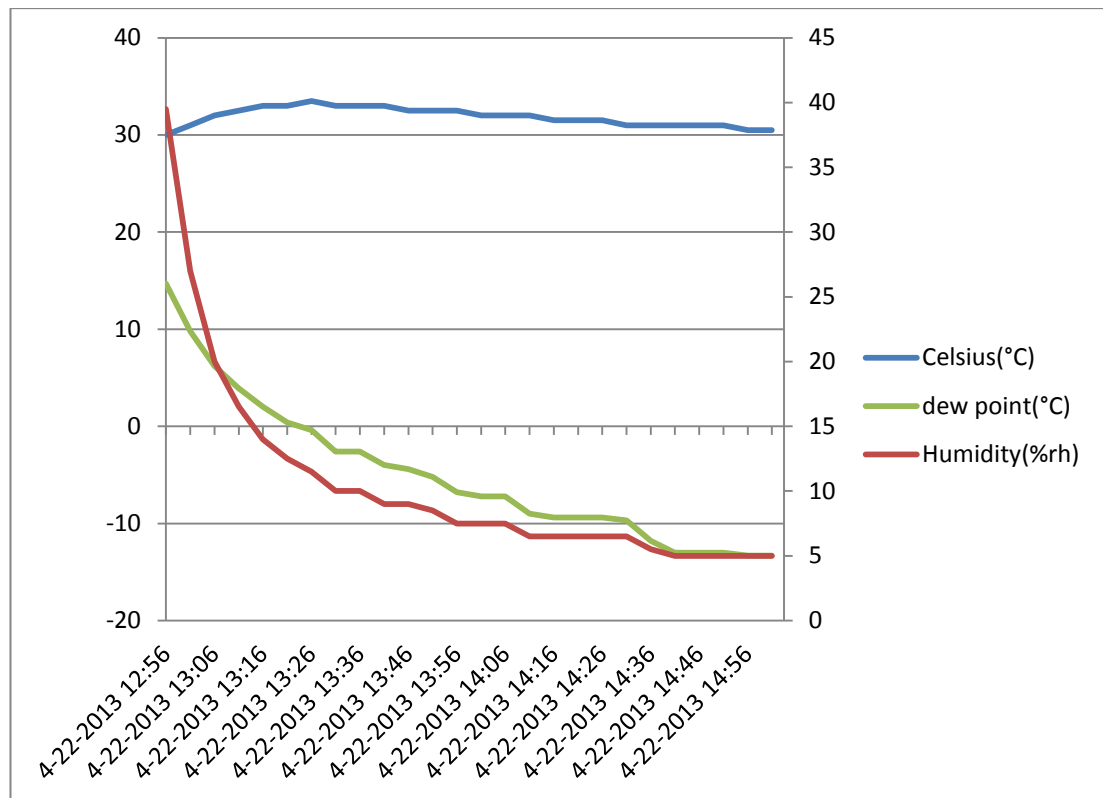


Fig c Relative humidity variation in airtight containers with tomato seeds at seed bead ratio of 1:0.75 for 2 hours

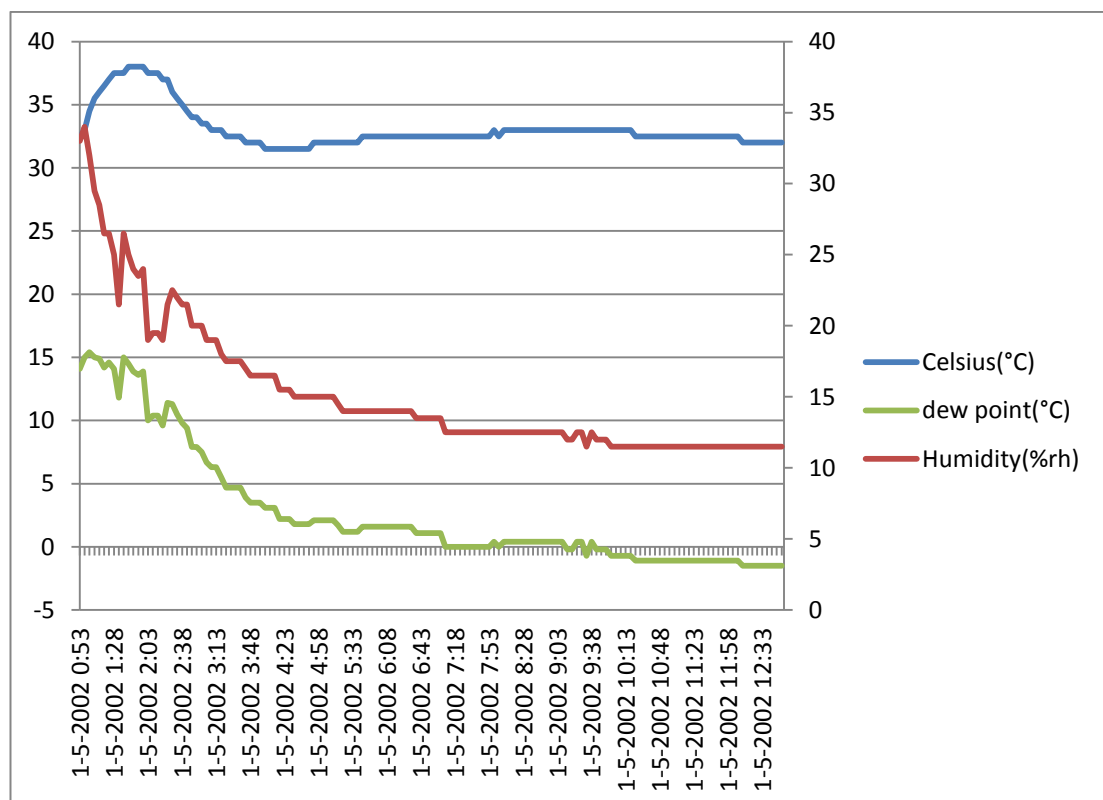


Fig d Relative humidity variation in airtight containers with tomato seeds at seed bead ratio of 1:0.5 for 12 hours

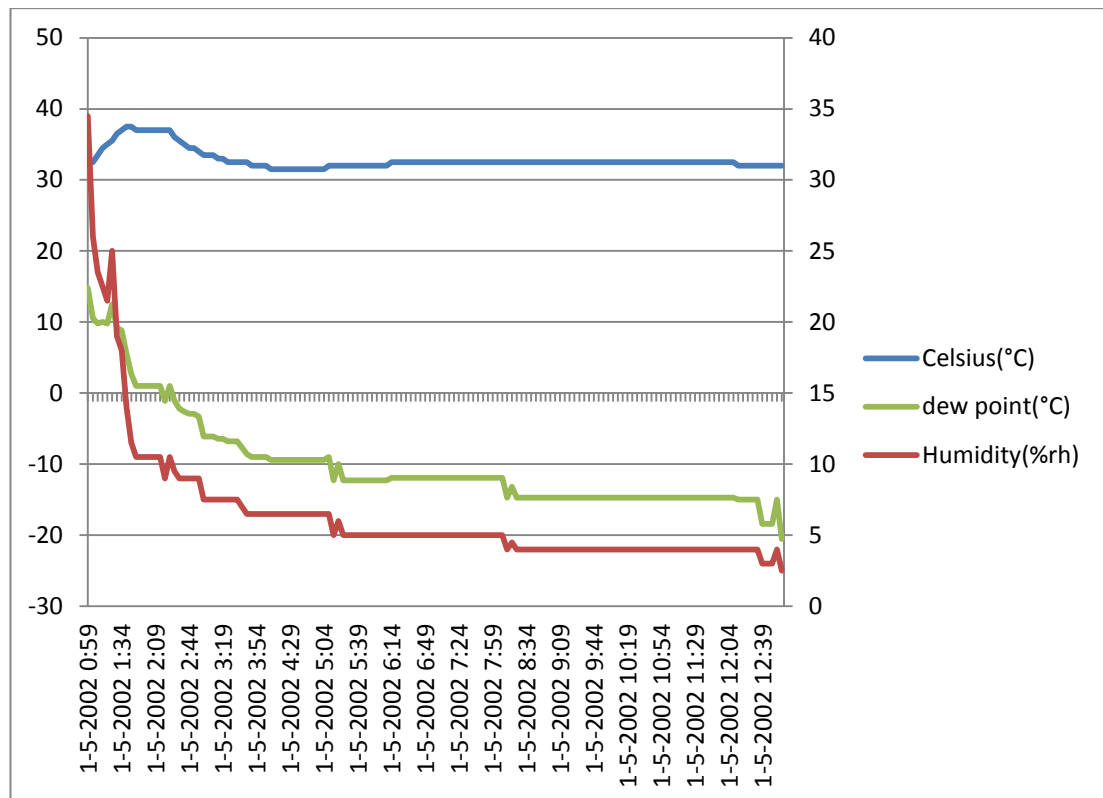


Fig e Relative humidity variation in airtight containers with tomato seeds at seed bead ratio of 1:1 for 12 hours

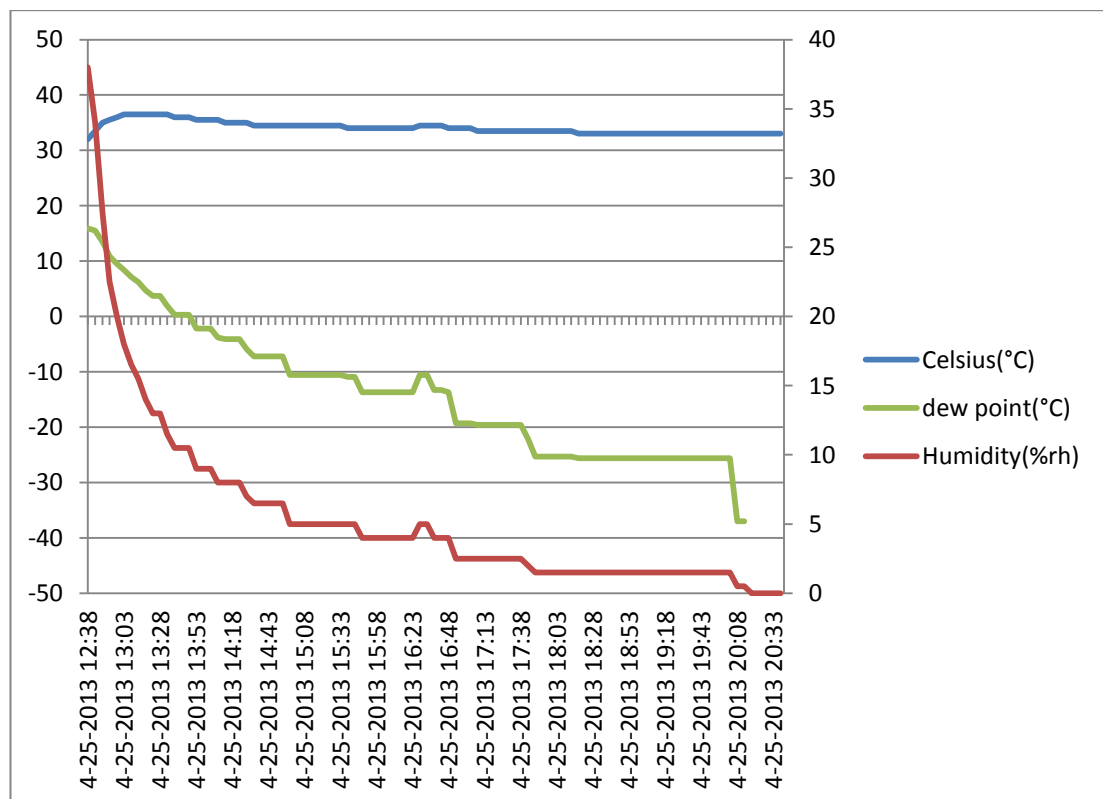


Fig f. Relative humidity variation in airtight containers with tomato seeds at seed bead ratio of 1:0.75 for 8 hours

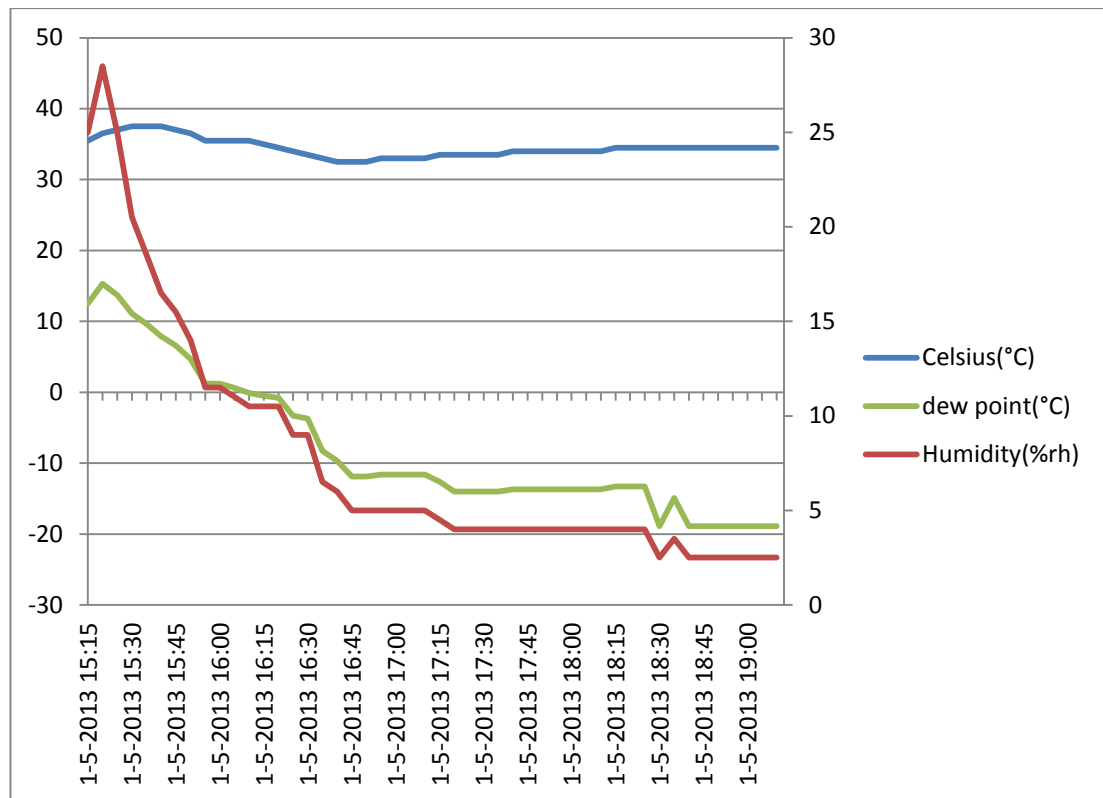


Fig g. Relative humidity variation in airtight containers with tomato seeds at seed bead ratio of 1:1 for 4 hours

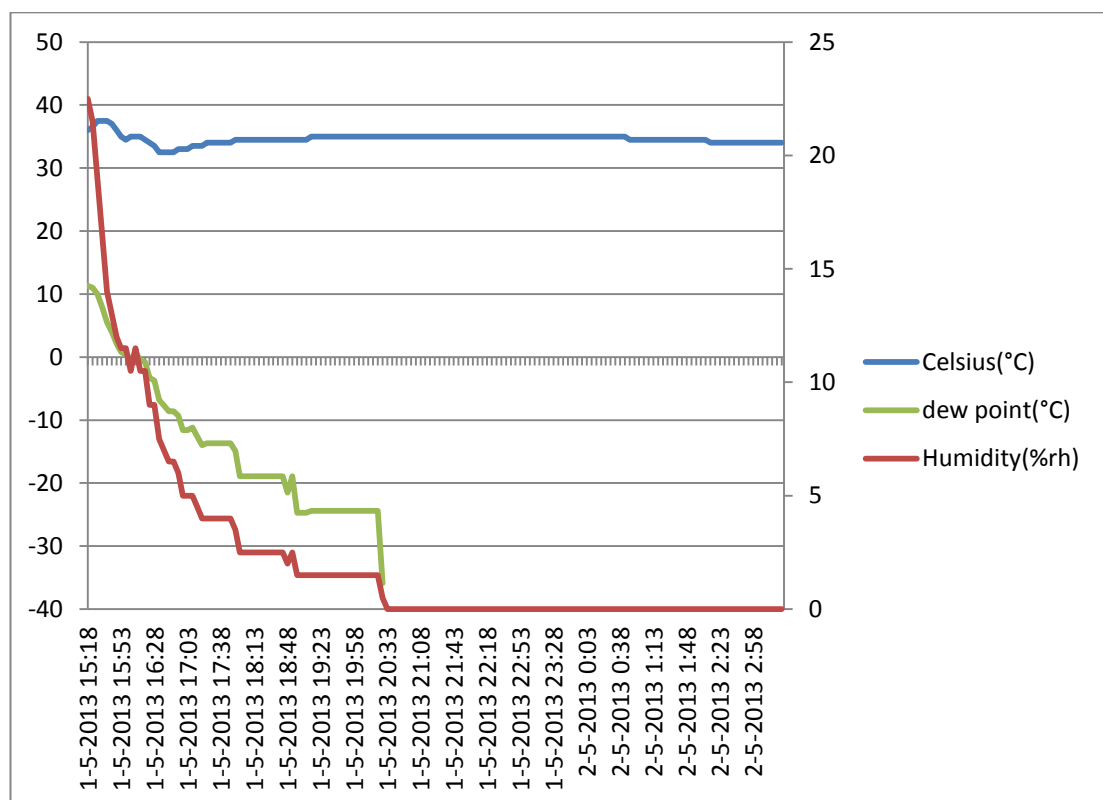


Fig h. Relative humidity variation in airtight containers with tomato seeds at seed bead ratio of 1:0.5 for 12 hours

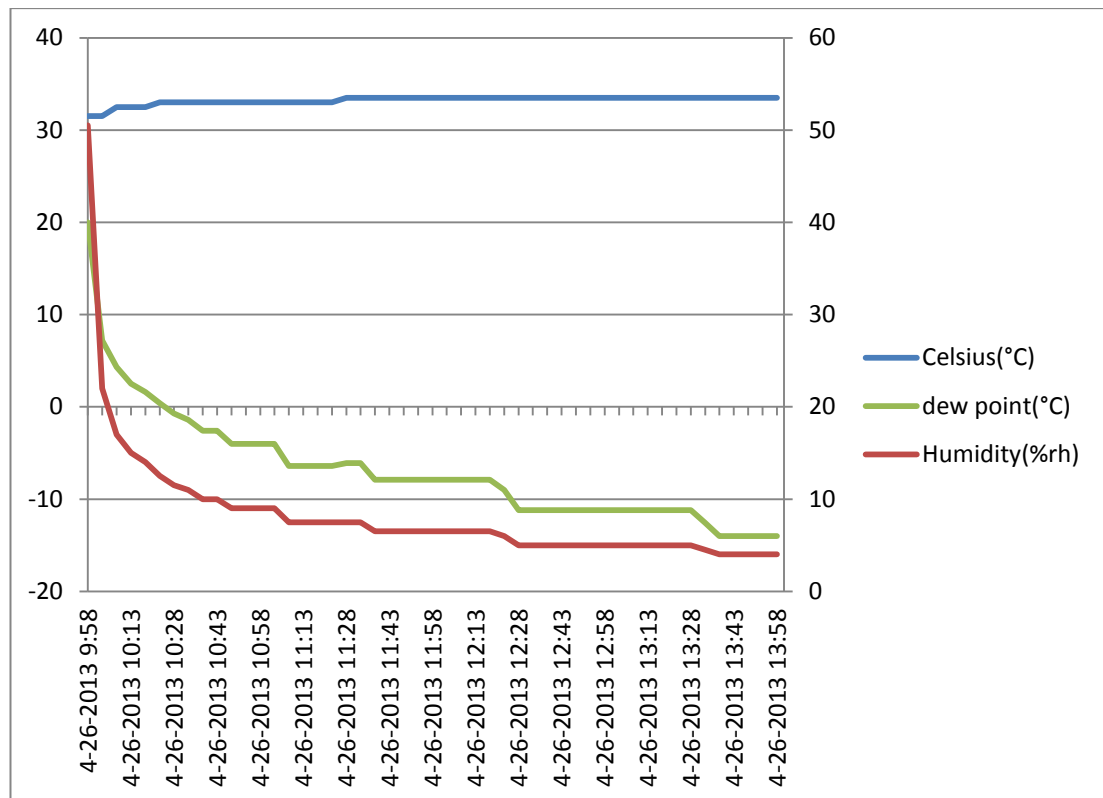


Fig i. Relative humidity variation in airtight containers with onion seeds at seed bead ratio of 1:1 for 4 hours

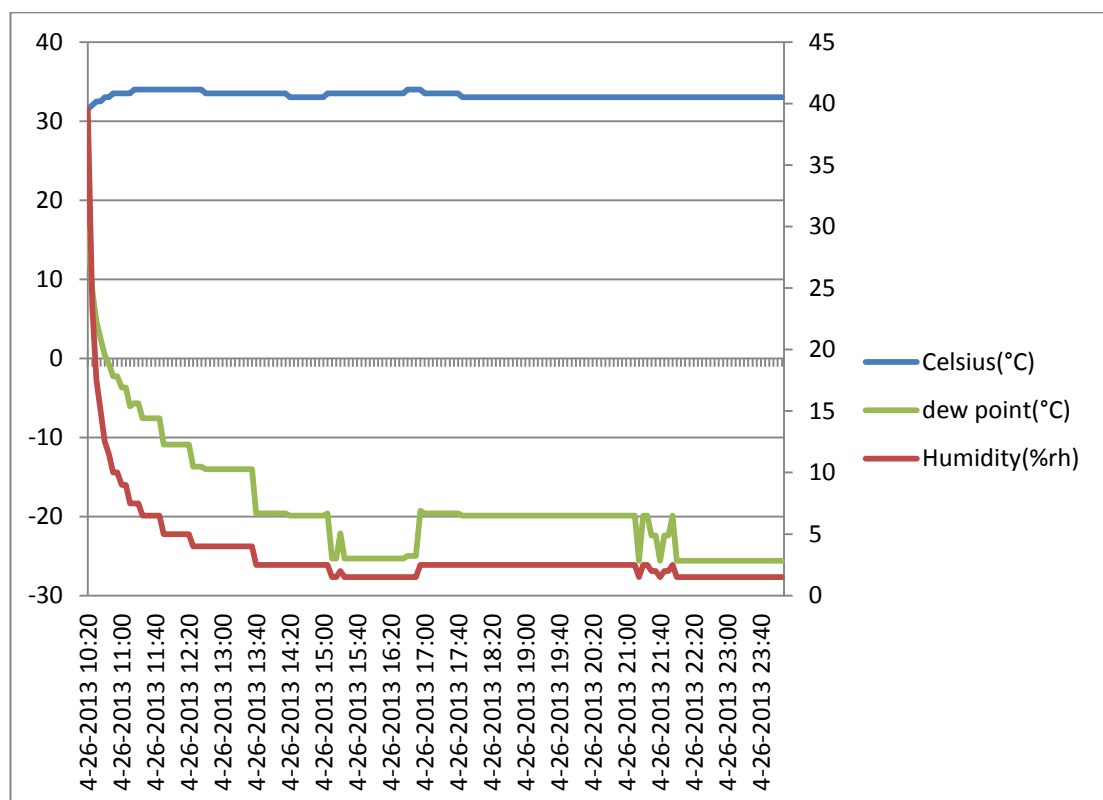


Fig j. Relative humidity variation in airtight containers with tomato seeds at seed bead ratio of 1:1 for 12 hours

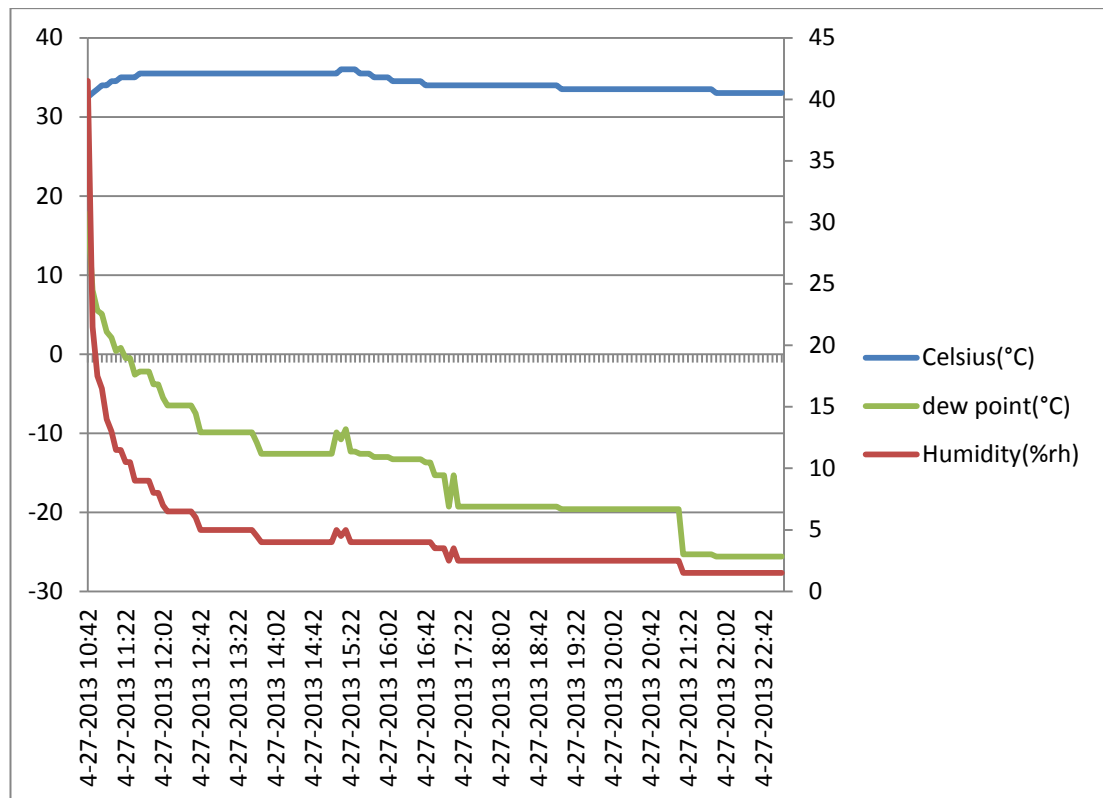


Fig k. Relative humidity variation in airtight containers with onion seeds at seed bead ratio of 1:0.75 for 12 hours

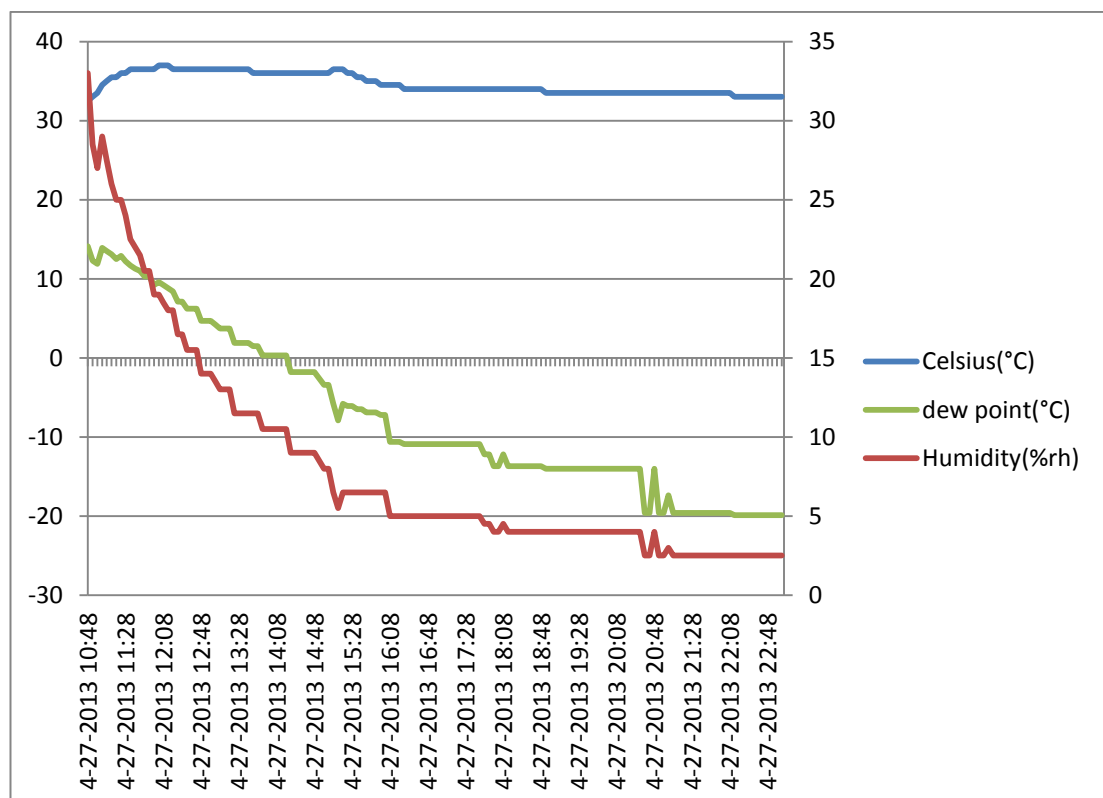


Fig l. Relative humidity variation in airtight containers with onion seeds at seed bead ratio of 1:0.5 for 12 hours